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A Laboratory Experiment

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Patents versus Subsidies

A Laboratory Experiment

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Abstract:
This paper studies the effects of patents and subsidies on R&D investment decisions. The theoretical framework is a two-stage game consisting of an investment and a market stage. In equilibrium, both patents and subsidies induce the same amount of R&D investment, which is higher than the investment without governmental incentives. In the first stage, the firms can invest in a stochastic R&D project which might lead to a reduction of the marginal production costs and in the second stage, the firms face price competition. Both stages of the game are implemented in a laboratory experiment and the obtained results support the theoretical predictions. Patents and subsidies increase investment in R&D and the observed amounts of investment in the patent and subsidy treatment do not differ significantly across both instruments. However, we observe overinvestment in all three treatments. Observed prices in the market stage converge to equilibrium price levels.

Keywords: R&D investment, oligopoly, patents, subsidies, experiment

JEL Classification: C90, L13, O31

1. Introduction

A bulk of evidence indicates that there is a positive effect of innovative activity on firm profits, productivity, economic growth and total welfare (see e.g. Kamien and Schwartz (1975) for a survey). However, many empirical studies investigating R&D investment behavior find that firms tend to underinvest in R&D compared to the socially optimal R&D investment level, e.g Bernstein (1996), Cohen (1995), Cohen and Levin (1989), Jones and Williams (1998, 2000), or Steger (2005). For instance, Jones and Williams (1998), p. 1133, state that "the optimal share of resources to invest in research is conservatively estimated to be two to four times larger than the actual amount invested by the U.S. economy." In general, underinvestment in R&D is mainly caused by the fact that firms' private returns of an innovation might be lower than social returns, see e.g. Griliches (1992). The reason for this inequality lies in the special properties of the good 'innovation' itself. A firm can only skim the maximal profit of an innovation if it is the exclusive owner of an innovation, e.g., if competing firms are prevented from imitating the innovation. Hence, the amount of R&D investment will depend on the degree of appropriability of an innovation and thus on the realizable profits of an investing firm.

In order to stimulate R&D spending governments use different policy instruments as incentives. Among frequently used instruments are patent protection of an innovation, subsidies for R&D investment costs, granting research joint ventures, or announcing research tournaments. All these instruments provide incentives to increase R&D investment, but they influence investment levels through very diverse channels. Patent protection is used to prohibit the imitation of the innovation by other firms (thus targeting at the revenue side of firms' profits), whereas subsidies are used to decrease R&D investment costs and thereby encourage investment and reduce the risk of an investment in case of failure (targeting at the cost side of firms' profits). Research joint ventures permit firms to cooperate in R&D (sharing risk and dividing gains) and research tournaments are competitions announced by government, often the military, in which an award is given to the company first succeeding in the wanted invention (note that in contrast to patent protection the rights of the invention are transferred to the sponsor of the tournament).[1]

[1] For an overview of different aspects of R&D spending and incentive instruments refer to Scotchmer (2005).

Especially the first two instruments are very common in various industries like consumer electronics, pharmaceuticals, or automobile. In the fiscal year 2007, for instance, 184,376 patents were granted in the U.S. (39.37% of the applications) and the U.S. government funded 9.22% (24,450 out of 265,193 millions of US-$) of the industry's R&D expenditures (see Performance and Accountability Report 2008 by the United States Patent and Trademark Office and Info Brief 2008 of the National Science Foundation). For Germany similar results are reported: 17,884 patents were granted in 2007 (30.74% of the applications) and the German government financed 4.5% (1,723 out of 38,651 millions of €) of the business enterprise sector's R&D expenditures (see Annual Report 2007 of the German Patent and Trademark Office and Research and Innovation in Germany 2008 of the Federal Ministry of Education and Research).

Due to the extensive application and the political and practical relevance of patents and subsidies we want to analyze the incentive effects of both instruments on firms' R&D investment decisions in this paper.[2] Contrary to empirical research which is based on real-world data, where always a mix of instruments is present and the induced effects are not easily distinguishable, we test in a controlled laboratory experiment how the induced incentives of each instrument actually perform in a direct comparison. Specifically, we compare (i) the impact of these instruments on firms' R&D investment with a benchmark situation without incentive providing instruments as well as (ii) which of the two instruments turns out to be more successful in stimulating R&D investments. However, note that we abstain from a welfare analysis, i.e., from analyzing the efficiency of the two instruments in terms of costs and benefits (e.g. due to difficulties in the comparability of both instruments' funding) and rather concentrate on the incentive effects of both instruments on investment behavior.

There exists a vast theoretical and empirical literature also including some experimental studies analyzing the effects, usage, design, and drawbacks of the four instruments[3] mentioned above. Patents might be one useful policy instrument to

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[2] According to the OECD (2004), p. 2, "(p)atenting has accelerated rapidly in the past decade, with the number of patent applications filed in Europe, Japan and the United States increasing by 40% between 1992 and 2002, from 600 000 to 850 000 per year. The effects of such patenting on incentives to innovate, on the diffusion of scientific and technical knowledge and on competition remain unclear and vary across industry sectors and technological fields." Our study is meant to shed further light on the incentive effects to innovate of the investigated instruments.

[3] For patents please refer to e.g. Reinganum (1983), or Sakakibara and Branstetter (2001); for subsidies to e.g. Spencer and Brander (1983), Hinloopen (2000, 2001), Görg and Strobel (2007), or Aerts and Schmidt

enhance R&D investment as they prohibit direct imitation which is seen as the main problem causing underinvestment compared to the socially optimal R&D investment level. The impact of granting patent protection is typically analyzed in dynamic patent race models (among others see Harris and Vickers (1987)).[4] In these studies patent protection of an innovation indeed increases equilibrium R&D investment. However, by creating a the-winner-takes-all situation, patent races might systematically induce excessive spending on R&D (i.e., higher than socially optimal investment levels) with negative effects on welfare (see e.g. Dasgupta and Stiglitz (1980), or Loury (1979)). Thus, although patents set incentives to increase investment level in R&D, drawbacks of strong patent protection turn out to be the risk of creating overinvestment in R&D and furthermore socially inefficient monopoly pricing of the winner. Experimental studies on a one-stage stochastic R&D process by Isaac and Reynolds (1986, 1988) also show that subjects spend more under full[5] than under partial appropriability and they observe that R&D investment exceeds the socially optimal amount under full appropriability.

Subsidies as another policy instrument are used to stimulate investment and to decrease the risk of firms investing in R&D since the costs in case of failure are reduced. Subsidies should encourage firms either to invest more or to overcome a threshold of investing in R&D. Theoretical work (see e.g. Hinloopen (2001)) concerning the impact of subsidies indicates that investment levels as well as welfare are increased, but that profits decrease.[6] An experimental study on the effects of subsidies and appropriability on stochastic R&D investment by Davis et al (1995) also proves that R&D investment is increased significantly by a subsidy. Other experimental studies on subsidizing R&D like those by Buckley et al (2003) and Cooper and Selto (1991) rather focus on the effect of different designs of the subsidy in form of tax benefits and R&D project funding (see Giebe et al (2006)).

(2008); for research joint venture to e.g. Suzumura (1992), Kamien et al (1992), or Suetens (2005) and for research tournaments to e.g. Moldovanu and Sela (2006), or Fullerton et al (1999, 2002).

[4] Among various aspects of patent laws that have been already studied in the economic literature are the optimal length and breadth of patents (e.g. Nordhaus (1969); Gilbert and Shapiro (1990); Klemperer (1990); Gallini (1992); Chang (1995)). There exist also studies on patent races focusing on the timing of investment and the different behavior of leaders and laggards see e.g. Breitmoser et al (2008), Zizzo (2002) and Kähkönen (2005).

[5] Full appropriability of an innovation means that the innovating firm gains the complete profits induced by the innovation, i.e., monopoly profits. Therefore full appropriability corresponds to patent protection.

[6] Note that a tax is used in those models to finance the subsidy.

The existing literature provides evidence that patents as well as subsidies seem to have a substantial impact on rising R&D investment. The aim of this paper is to make a first attempt to *directly* compare the effect of patent protection and subsidies on firms' investment in R&D by running a controlled laboratory experiment. Particularly, we investigate the questions whether patents and subsidies encourage R&D investment into a cost reducing technology (process innovation) at all compared to the baseline case without governmental incentives and which of the two instruments actually leads to higher R&D spending thus providing a stronger investment incentive in the experimental setting. Our experimental data (i) ensure that only one of the instruments is present at a time and thereby (ii) enable us to study the influence of each instrument separately and thus to compare them in a controlled setting.

The experiment consists of a two-stage game in which at a first stage subjects are asked to invest in an uncertain R&D project followed by a market stage with Bertrand price competition.[7] Investment behavior in R&D on the basis of two-stage games is investigated experimentally by e.g. Jullien and Ruffieux (2001), Suetens (2008) and Isaac and Reynolds (1992). Note that by additionally implementing a market stage (second stage of the game), a firm's private returns from R&D are determined endogenously at this Bertrand competition stage (by price setting and demand) and are not exogenously given. Following Dufwenberg and Gneezy (2000) who find that three firms are enough to let prices converge to equilibrium prices in Bertrand games, a market is assumed to consist of three competing firms.

Three treatments are run: one with patent protection, one with subsidizing (lower investment costs), and - as a benchmark - one without incentive instruments. In order to make patent protection and subsidizing perfectly comparable, the experimental parameters for both incentive instruments are chosen in a way that in equilibrium the profit maximizing investment for firms and thus the social welfare evolving from both are equal. Specifically, in our model the patent protects the innovation during the whole market duration and the subsidy is chosen in such a way that the investment induced will equal the investment under patent protection in equilibrium. Our experiment provides evidence that subsidies and patents have a significantly positive impact on

[7] A Bertrand market is chosen for simplification in the experiment and to follow the patent race literature which often uses a the-winner-takes-all assumption, for a general model see Harris and Vickers (1987). In our setting only an exclusive innovating firm can reap all profits at the market stage, the other firms receive nothing.

R&D investment and that the effect of both instruments on incentives to innovate is similar. However, our experiment also shows that firms seem to fail to provide their profit maximizing R&D effort as they overinvest compared to their theoretically predicted equilibrium level. This implies dissipation of rents since we observe in both treatments that welfare on the society level is smaller than in equilibrium.

The remaining part of the paper is structured as follows. Section 2 presents the theoretical model, which is followed by the experimental design and proceedings in Section 3. Section 4 encloses the experimental results and with a discussion, in Section 5, we conclude.

2. The Model

Consider the following two-stage game with i=1,...,n risk-neutral firms. Table 1 shows the structure of the game: At the first stage ('R&D investment stage'), each firm starts out with identically high marginal costs $c_i^H = c^H$, $\forall i$, and independently decides on the amount it invests in R&D, $r_i \in [0,1]$, to gain low marginal costs, $c_i^L = c^L > 0$, $\forall i$, with $0 \le c^L < c^H$.[8] Firm i's probability of successful R&D is given by a continuous cumulative distribution, $F(r_i)$, with density $f(r_i)$, and we assume $F(0) = 0$, $F(1) = 1$, and that $F(\cdot)$ is monotone and concave (i.e., $f(r_i) > 0$ and $f'(r_i) < 0$ for $r_i \in [0,1]$, respectively). In words, we assume constant marginal costs and diminishing returns from R&D investment.[9] At the second stage ('market stage'), t=1,...,T consecutive Bertrand market periods take place in each of which firms simultaneously set their prices, $p_{i,t}$, at which they sell a homogeneous good.[10] Consumers only buy at the lowest market price, $p_t^{\min}$, and we assume the same (normalized) price-inelastic market demand in each period, Q=Q_t=1, $\forall t$.[11] In the first Bertrand market period, each firm's

[8] Each firm chooses privately and simultaneously an R&D investment level.

[9] Although it is debated whether R&D investments exhibit diminishing returns in the empirical literature, we follow the theoretical papers in the tradition of d'Aspremont and Jacquemin (1988). For comments on that matter please refer, e.g., to Kamien and Schwartz (1975), Griliches (1990), and Nadiri (1993). We also refrain from modeling fix costs, *FC*, as we do not analyze any decisions to enter the market.

[10] For simplicity, we assume that firms only produce when they can sell.

[11] An implication of assuming price-inelastic demand is that the innovation will be automatically non-drastic since the monopoly price before and after the innovation (which equals the prohibitive price $\overline{p}$) is assumed to be higher than c^H.

marginal costs, c^H or c^L, only depend on its own success in the R&D investment stage.[12] We assume, without loss of generality, that high cost firms can then imitate the production technology of low cost firms at no cost and also produce at c^L beginning in the second market period. Thus, in absence of any imitation-prohibiting policy, a firm's marginal costs in the second and all subsequent market periods depend not only on its own success but also on whether or not at least one firm has successfully innovated in the first period.

Table 1: Structure of the two-stage game

1st stage	n firms invest each $r_i \in [0,1]$ and receive with probability $F(r_i)$ low marginal costs c^L; investment costs are $(1-\sigma)r_i$	single investment decision
2nd stage	firms have either low (c^L) or high marginal costs (c^H) and set prices $p_{i,t}$ in each period	$1,...,T$ Bertrand market periods
	• low marginal costs c^L cannot be imitated	• 1st market period
	• low marginal costs c^L are protected from imitation by a patent	• $\theta = 0,1,...,T-1$ market periods
	• low marginal costs c^L can be imitated	• $T-\theta-1$ market periods

We examine two common government R&D policies that influence the firms' incentives to invest in R&D: *subsidies* and *patents*. Subsidies target at the cost side of each firm's expected profit from R&D by covering a proportion $\sigma \in [0,1]$ of its R&D costs (i.e., each firm *i* pays $(1-\sigma)r_i$ and government pays σr_i). Patents, in contrast, target at the revenue side of each firm's expected profit by protecting innovating firms beyond the first period. More precisely, government prohibits high cost firms to apply imitated production technologies for other $\theta = 0,1,...,T-1$ market periods after the first market period. Note that each successfully innovating firm obtains patent protection in our model, i.e., more than one firm in a market might be provided with a patent. Thus, patent protection does not automatically create a monopoly. One might argue that this is no 'pure' patent protection (in the sense of 'the winner takes all'). However, it is realistic to assume that firms might invest in different technology innovations yielding a cost reduction and that these different technologies are protected. Finally, we assume that the game structure and parameters as well as the R&D success of each firm and the government R&D policy (hence the marginal cost of each firm in each market period) are common knowledge. In the next subsections we analyze our two-stage game. Due to

[12] We assume that there are no technological spillovers at the investment stage: each firm *i*'s chances of a successful innovation depend only on its own investment r_i, not on a rival's investment r_j.

backward induction we start the analysis with the second stage of the game followed by the first stage.

2.1 Market stage

Depending on the government's R&D policy and the firms' R&D successes at the first stage, we distinguish between different compositions of marginal costs in each Bertrand market which lead to different market prices (for simplicity, we refrain from indexing R&D policies and market periods). We assume that among the firms which offer the lowest price those with the lowest marginal costs share the demand equally.

(i) The market price equals the lowest marginal costs in the market and is thus either $p^* = c^H$ or $p^* = c^L$. $p^* = c^H$ is the market price if *no firm has low marginal costs* and $p^* = c^L$ is the market price if *at least two firms have low marginal costs*. Hence, the market profits for all firms are $\pi^* = 0$.

(ii) A market price higher than the lowest marginal costs is set if merely *one firm has low marginal costs*. This firm sets a price as high as the competitors' marginal costs, i.e. the market price equals high marginal costs, $p^* = c^H$. Thus, the firm with low marginal costs receives positive market profits $\pi_i^* = p_i^* - c^L \equiv c^H - c^L > 0$ while the competitors receive zero market profits $\pi_{-i}^* = 0$, $\forall -i \neq i$.

For a more detailed derivation of the market prices, see, for instance, Motta 2004.

Note that (*ii*) may apply to the first market period and all periods that are patent protected by government, but in all other cases either no firm or all firms have low marginal costs. Moreover, note that market prices as well as Nash equilibrium profits are unique for each cost structure (though there are infinitely many Nash equilibrium price constellations) and that the only equilibrium situation in which a firm makes strictly positive market profits is in case it is the only low cost firm.

2.2 R&D investment stage

In this subsection we analyze the investment decision at the first stage. In the following we concentrate on the case that all firms' R&D investments are symmetric (i.e., $r_i \equiv r$, $\forall i$) as a benchmark case. Note that there might also exist asymmetric equilibria. We will discuss the equilibrium selection in more detail in Sections 3.1 and 4.1. At the R&D investment stage, each firm knows the government's R&D policy and anticipates all possible Nash equilibrium profits at the market stage.

Proposition 1 (R&D investment levels) *The symmetric Nash equilibrium level of R&D investment, $r^*(n,\Delta c,\theta,\sigma)\in[0,1]$, is characterized by the necessary and sufficient condition*

$$f(r^*)\left[1-F(r^*)\right]^{n-1}(1+\theta)\Delta c=1-\sigma. \qquad (1)$$

The optimal investment level in R&D r^* is increasing in the mark-up from being the only low cost firm $\Delta c = p-c^L = c^H - c^L$, the number of patent-protected periods θ, and the subsidized proportion of the firms' R&D investment costs σ. However, r^* is decreasing in the number of firms n; and it is independent of the number of market periods T.

The proof is given in the Appendix A1.

Proposition 1 implies that both policy instruments provide incentives for the firms to increase their investment levels in R&D. Moreover, as a firm can only achieve positive profits under Bertrand competition if it is the sole innovating firm in its market, the incentive to invest in R&D increases the higher this mark-up is. In our model investment levels decrease with tougher competition (i.e. an increase in *n*), because it becomes less probable that a firm is the sole innovator the more competitors are in the market. Note that there is huge literature studying the impact of market structure on investment behavior providing mixed results (for studies on the different effects of competition on investment see e.g. Boone (2000), Schmutzler (2007), Vives (2006), or Sacco and Schmutzler (2008) for an experimental investigation).[13] The equilibrium value of *r* is independent of the number of market periods *T*, but dependent of the number of patent-protected market periods θ. Since the number of market periods in which a single low cost firm can make positive profits is in our model reduced to the first period and in the patent case determined by the additional number of patent-protected market periods θ.

[13] Cohen and Levin (1989, p. 1075) already stated that "[e]conomists have offered an array of theoretical arguments yielding ambiguous predictions about the effects of market structure on innovation."

2.3 Distributional effects

In this subsection we distinguish the welfare shares (or rents) of the different interest groups (firms, consumers and government) in order to analyze the effects of an increase in the subsidized proportion and in the number of patent-protected periods, respectively. Thereby, we do not focus on absolute changes of the rents, but rather on rent shifting between different interest groups. Given equilibrium behavior of the firms (i.e., the symmetric Nash equilibrium investment level of $r_i^*(\sigma,\theta) = r^*(\sigma,\theta)$, $\forall i$), we investigate the impact of each policy instrument on added rents.[14] Proposition 2 indicates that different policy instruments have different distributional consequences.

Proposition 2 (Rent shifting) *An increase in the subsidized proportion of the firms' R&D investment costs induces a transfer from government to firms as well as expected rent shifting between consumers and firms; an increase in the number of patent-protected market periods induces as well expected rent shifting between consumers and firms.*

The proof is given in the Appendix A1.

However, note that the sign of the shifted transfers between consumers and producers depends on the concrete parameterization. Precise predictions for our experimental setup are derived in the next section in order to analyze which group benefits from an introduction of subsidies and patents, respectively.

3. Experimental predictions and design

In the first section, we parameterize the model to derive the hypotheses for the experiment and in the second section, we describe the experimental design.

3.1 Experimental set-up: Equilibrium predictions and hypotheses

Table 2 summarizes the treatment parameters of our experimental set-up.[15] Specifically, we use the continuous cumulative probability distribution of R&D success

[14] Note that we use *added* rents, i.e., we consider the change of actual total rents in case firms invest in R&D in comparison to the situation in which no firm invests in R&D.

[15] In the following the standard case with no instrument is called *NO*, the subsidy case is called *SUB* and the patent case *PAT*.

$F(r_i) = \frac{1}{10} r_i^{0.5}$, $\forall r_i \in \{0,99\}$, with density $f(r_i) = \frac{1}{20} r_i^{-0.5}$ and $f'(r_i) = -\frac{1}{40} r_i^{-1.5}$, and n=3, c^H=500, c^L=100 and T=2. As the market stage consists only of two market periods and a cost reduction can only be imitated in the second period, we set the patent-protected rounds equal to $\theta = 1$ $(\theta = T-1)$, i.e., the patent protects the innovation during the whole market duration T. The subsidy proportion $\sigma = \frac{1}{2}$ is chosen such that the two policy instruments (patents and subsidies) induce equal symmetric Nash equilibrium investment levels.

Table 2:Treatment parameters

Treatment	Investment costs	Cost structure 1st market period	Cost structure 2nd market period	Number of independent observations (sessions)
NO	r_i	$c_{i,1} \in \{c^L, c^H\}$	$c_{i,2} = \min[c_{1,1}, c_{2,1}, c_{3,1}]$	5(1)
SUB	$0.5r_i$	$c_{i,1} \in \{c^L, c^H\}$	$c_{i,2} = \min[c_{1,1}, c_{2,1}, c_{3,1}]$	5(1)
PAT	r_i	$c_{i,1} \in \{c^L, c^H\}$	$c_{i,2} = c_{i,1}$	5(1)

The cost structure is given by $c_{i,t}$, where i denotes the firm and t the market period.

The continuous equilibrium predictions which will be used as a benchmark for our data analysis are given in Table 3 for our concrete parameters.[16] The equilibrium R&D investments lead to the same added welfare in *SUB* and *PAT* which is higher than in *NO*.[17] Comparing the effect of an introduction of each R&D policy instrument with the situation without policy instruments Table 3 indicates that an introduction of subsidies decreases the firms' expected added profits and government rent, and increases expected added consumer rent. The introduction of patent protection increases the firms' expected profits and decreases expected consumer rent. Thus, in our concrete experimental set-up the introduction of a subsidy partly shifts rents from firms to consumers and the introduction of a patent partly shifts rents from consumers to firms.

[16] Derivations of equilibrium investment levels are given in the Mathematical Appendix D2. Note that the presented investment levels are the symmetric Nash equilibria. In *SUB* and in *PAT* in addition there exist three asymmetric Nash equilibria given by (56.25, 56.25, 6.25).

[17] The formula for added welfare is given in the Mathematical Appendix D3. The individual welfare shares (added consumer, producer and government rent) are given in the proof of Proposition 3.

Table 3: Experimental predictions

Treatment	Nash equilibrium investment	Added welfare	Added consumer rent	Added producer rent	Added government rent
NO	25	625	550	75	0.00
SUB	37.16	640.92	640.90	55.76	-55.74
PAT	37.16	640.92	529.40	111.51	0.00

For the derivation of welfare shares we use the continuous symmetric Nash equilibrium investment levels given in Table 2 as well as T=2, $\theta = 1$, $\sigma = 0.5$ and $\Delta c = 400$.

The symmetric Nash equilibrium investment level and the corresponding implications for welfare shares yield testable predictions about the incentives to invest in R&D. Let us summarize our main experimental hypothesis which will be tested in Section 4:

Hypothesis 1: (*Investment levels*) Investment levels increase if a policy instrument (*SUB*, *PAT*) is introduced.

Hypothesis 2: (*Welfare*) Welfare increases if a policy instrument is introduced.

Hypothesis 3: (*Special interests*) Consumers prefer *SUB* to *NO* to *PAT*, firms prefer *PAT* to *NO* to *SUB*[18].

3.2. Experimental design and procedures

The computerized[19] experiment was conducted at the Cologne Laboratory for Economic Research in December 2005. We ran 3 sessions (baseline (*NO*), subsidy (*SUB*) and patent (*PAT*) treatment) each with 30 subjects.[20] Each session lasted about 1.45 hours (cf. the Appendix for the instructions). Earnings in the experiment were expressed in points. At the end of a session, point earnings were transferred to cash at an exchange rate of 300 points = 1 €. Subjects earned on average 14.95 € including a 2.50 € show-up fee (average earnings amount to: 16.53 € in Session 1 (*PAT*), 13.84 € in Session 2 (*SUB*) and 14.48 € in Session 3 (*NO*).

Each session consists of 30 decision rounds. At the beginning of the experiment, subjects are randomly divided into 5 matching groups of 6 subjects each. At the beginning of each round 3 subjects (i.e., 'firm' 1, 2, and 3, respectively) are randomly

[18] Note, firms prefer *NO* to *SUB* because the firm's expected profit is higher in *NO* than in *SUB*. The reasoning is that the effect of the higher probability of being the alone innovating firm due to the lower investment in *NO* overweighs the effect of the lower investment costs in *SUB*.
[19] The experimental software was programmed using z-Tree (Fischbacher 1999).
[20] Subjects were recruited using ORSEE (Greiner 2004). The vast majority (96%) of subjects were undergraduate students from the University of Cologne, mostly belonging to the faculty of management, economics and social sciences.

matched.[21] Though subjects know they are randomly re-matched in each round, they are not informed that this happens within matching groups. Hence, each session provides us with five independent observations.

Each round of the 30 rounds is divided into two phases. Phase 1 corresponds to the investment stage and phase 2 to the market stage with two consecutive market periods *T*=2 (labeled phase 2A and 2B, respectively). In the *NO* treatment, each subject receives an endowment of *B*=100 points at the beginning of each round. In phase 1, each subject has to make an investment decision by choosing an integer of $r_i \in \{0,1,...,99\}$ points, which is subtracted from his endowment *B*. Moreover, each subject starts with high production costs of $c_i^H = 500$ points. Depending on the investment decision r_i and chance, represented by the realization of the cumulative probability function $F(r_i) = 0.1(r_i)^{0.5}$,[22] an innovation may occur which decreases production costs to a lower level of $c_i^L = 100$ points.[23] At the beginning of phase 2, each subject is informed about whether or not he successfully innovates, i.e., achieves lower production costs, and also about the innovation success of the other two subjects in his group (but not about their investment decisions). Thereafter, the first Bertrand market (phase 2A) starts, in which each subject has to submit a price $p_{i,1} \in \{c_{i,1}, c_{i,1}+1,...,1000\}$ between his own production costs $c_{i,1} \in \{c_{i,1}^L, c_{i,1}^H\}$ and a prohibitive price of 1000 points. The $n_1 \in \{1,2,3\}$ subjects with the lowest submitted price in the market can sell their goods[24] each earning $\pi_{i,1} = \frac{1}{n_1}(p_{i,1} - c_{i,1})$ points in the first market, whereas subjects with higher prices earn nothing (zero points). Each subject is informed about the lowest price

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[21] We use strangers matching to avoid cooperation in a repeated game and to retain the one-shot character. Price competition experiments show that three firms are sufficient to ensure near Bertrand-equilibrium prices (see Dufwenberg and Gneezy (2000)).

[22] To simplify matters r_i is divided by hundred, since this allows subjects to choose integer numbers between 0 and 99 in the experiment instead of decimals. Note that by excluding an investment level of 100 cost reduction remains stochastic even for the maximum investment.

[23] In the experiment subjects are given a table which specifies the investment costs and the probability of a cost reduction (i.e., a successful innovation) for each possible investment level. Given a subject's investment decision, the computer program randomly determines based on the corresponding cumulative probability function $F(r_i)$ whether or not the subject 'innovates', i.e., achieves lower production costs (for more details of these procedures and the given table see the instructions in the Appendix).

[24] In order to make the design as simple as possible for the subjects, those subjects with the lowest price share the demand equally. Thus, we relax the assumption of our model that among those firms which offer the lowest price only those with the lowest marginal costs share the demand. Note that this implies that the achievable mark-up of a sole innovator decreases to $\Delta c = 399$, since its equilibrium price decreases to 499.

and his own profit in the first market, but no other information is given. In the second Bertrand market (phase 2B), due to costless imitation opportunities, each subject starts with the lowest production cost among the firms in the first market $c_{i,2} = \min[c_{1,1}, c_{2,1}, c_{3,1}], \forall i$. The procedure in the second market is exactly the same as in the first market: those subjects with the lowest price (n_2) obtain profits of $\pi_{i,2} = \frac{1}{n_2}(p_{i,2} - c_{i,2})$ points and those with higher prices zero-profits. At the end of each round, each subject i is informed about his round profits, which are given by $\pi_i = \pi_{i,1} + \pi_{i,2} - r_i + B$, and his total profits so far.

In the *PAT* treatment, exactly the same procedure as in *NO* is applied, with the only difference that imitation in the second Bertrand market is prohibited ($\theta = 1$): Each subject's production costs in the second market are equal to his own costs in the first market $c_{i,1} = c_{i,2}, \forall i$. Finally, the *SUB* treatment differs in only one aspect from *NO*: As half of the investment costs are subsidized ($\sigma = \frac{1}{2}$), a firm's investment costs are reduced from r_i to $0.5r_i$ (compare also Table 2).

4. Experimental results

The presentation and analysis of our experimental data are organized as follows. We start by examining R&D investment levels (4.1) including investment dynamics over time and individual behavior. Thereafter, we investigate firms' price setting and resulting profits in the Bertrand markets (4.2). Finally, we analyze the effects of subsidies and patents on social welfare as well as on welfare for special interest groups, i.e., firms, consumers and government (4.3). In case average results are presented, the term average refers to mean value over rounds in the subsequent analyses. Laboratory findings and their comparisons with the respective Nash predictions are summarized as *experimental results* (ER) at the end of each section.

4.1 R&D investments

Table 4 shows the average R&D investment for each treatment and the predicted symmetric Nash equilibrium for continuous investment levels.[25] At first sight, there are

[25] We take the continuous symmetric Nash equilibrium as a benchmark. Note that we get multiple equilibria in case of discrete investment levels (all equilibria are given in Table A1 in the Appendix). However, continuous and discrete equilibria do not differ (much) as long as we concentrate on symmetric equilibria (discrete symmetric equilibria are 25, 37, 37 in *NO*, *SUB*, *PAT*).

two remarkable aspects. First, the observed investment level is higher using a policy instrument like subsidy or patent in comparison with our baseline treatment with no R&D policy: Subsidies and patents increase firms' R&D investment levels by 35.79% and 45.62%, respectively. This indicates that both instruments serve the purpose of rising investment levels supporting Hypothesis 1.[26] Using matching group averages as independent observations a Kruskal-Wallis test reveals that we can reject the hypothesis that the investment levels of all treatments are drawn from the same population.[27] Pair wise Mann-Whitney-U tests reveal significant differences between *NO* and *SUB* as well as between *NO* and *PAT* whereas *SUB* and *PAT* investment levels do not differ significantly.[28] Second, the observed average R&D investment in the experiment is always higher than the predicted Nash equilibrium for each treatment. R&D investments are about 37.92% (26.00%; 35.12%) higher than theoretically predicted by the symmetric Nash equilibrium in *NO* (*SUB*, *PAT*). We will later discuss possible explanations for this overinvestment.

Table 4: Average observed and predicted R&D investments

Investment levels	*NO*	*SUB*	*PAT*
Observed	34.48 (23.67)	46.82 (32.13)	50.21 (35.61)
Predicted	25	37.16	37.16

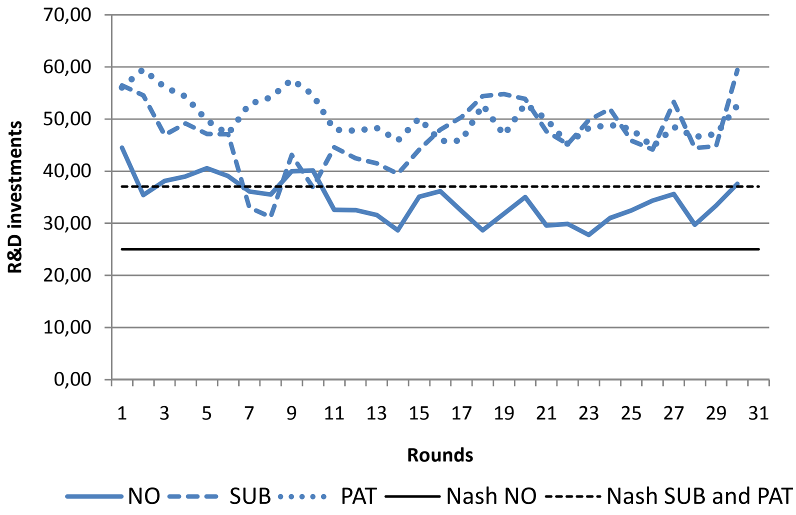
Standard deviations are given in parentheses.

4.1.1 Time path of investment

Figure 1 depicts observed and predicted average R&D investment levels per round. These levels are higher than predicted by the symmetric Nash equilibrium in all rounds in each treatment (with only three exceptions in *SUB*). Considering investment behavior over time, average R&D investment levels decrease from the first to the second half of 30 rounds in *NO* and *PAT* (36.59 vs. 32.36 and 52.14 vs. 48.28, respectively), but increase in *SUB* (43.81 vs. 49.82). However, Wilcoxon Signed Rank tests yield significant results only for the decrease in investments in *NO* at the 5% significance level.

[26] However, note that the theoretical increase in investment levels is higher: Investment levels are predicted to be 48.64% higher in *SUB* (and *PAT* respectively) than in *NO*.
[27] In the following nonparametric tests we always use matching groups as independent observations.
[28] One-tailed Mann-Whitney-U tests reject the null hypothesis of no differences in average investments in favor of higher investment levels in *SUB* and *PAT* than in *NO* (p=0.016) respectively (p=0.004), but cannot reject the null hypothesis for the comparison of *SUB* and *PAT* (p=0.21).

Figure 1: Observed and predicted R&D investments over rounds



To examine the dynamics of R&D investment decisions at the individual level, we use a simple ordinary least squares regression (Table 5). Due to dependency of the observations within matching groups we calculate clustered standard errors. As explanatory variables we consider treatment dummies and dummies for firm *i*'s success in reducing its cost in the previous round (i.e., lagged variables) as well as round dummies. The treatment dummies (*NO*, *SUB*, *PAT*) are used to generate interaction variables with the explanatory variables. In model (1) in Table 5 we consider dummies for a cost reduction due to successful innovation of a firm in the previous round CR_{t-1} (CR=1 for successful innovation, CR=0 for no innovation), where t denotes the round. Round dummies given for the first half of rounds (round 1-15) and the second half of rounds (round 16-30) as the base category are considered additionally in model (3). Moreover, in the estimated model (2) in Table 5 cost reduction dummies CR are subdivided into the cases that only firm i successfully reduced its costs ($CR1_{t-1}$), that firm i and one other firm j reduced their costs ($CR2_{t-1}$), and that all three firms reduced their costs in the previous round ($CR3_{t-1}$). Note that in all these categories at least firm i successfully innovates. The reference category for the three cost reduction dummies ($CR1_{t-1}$, $CR2_{t-1}$, $CR3_{t-1}$) is the situation that firm i did not have low costs in the previous round independent of the other firms' cost levels ($CR0_{t-1}$).

Model (1) in Table 5 shows that a successful innovation of firm i in the previous round has a positive and highly significant influence on its current investment level compared to the reference category 'no success' (CR=0). Moreover, the coefficients of all single cost reduction dummies in model (2) have a positive sign and are significantly different from zero as well: Independent of the treatment a firm *i* invests significantly more in the current round if at least this firm *i* successfully innovated in the previous round compared to the benchmark case that firm *i* had no success. Note that the investment level also increases if one or even both other firms in the market were also successful in cost reduction in the previous round. Note as well that being the exclusive innovator increases investment levels strongest (compare Table A2 in the Appendix, where we drop *CR1* as the base category; the coefficients for all other cost reduction dummies are negative compared with *CR1*). In line with the results from above we observe a round effect in *NO*: We find that investment levels in *NO* are significantly higher being in the first half of rounds (first round excluded) compared to the last half of rounds, whereas investment levels are significantly lower in the first half of rounds in *SUB* and are not significantly influenced by round in *PAT*.

Table 5: OLS regression results

	(1)		(2)		(3)	
Investment	Coefficient	(St. er.)	coefficient	(St. er.)	coefficient	(St. er.)
NO	28.26^{***}	(2.604)	28.26^{***}	(1.962)	26.67^{***}	(2.347)
SUB	31.78^{***}	(2.086)	31.78^{***}	(1.265)	34.84^{***}	(1.626)
PAT	27.90^{***}	(3.671)	27.90^{***}	(4.007)	27.33^{***}	(3.663)
$CR_{t-1}*NO$	11.18^{***}	(2.226)			11.09^{***}	(2.204)
$CR_{t-1}*SUB$	23.34^{***}	(3.096)			23.09^{***}	(2.983)
$CR_{t-1}*PAT$	37.49^{***}	(3.884)			37.40^{***}	(3.906)
$CR1_{t-1}*NO$			15.82^{***}	(2.607)		
$CR1_{t-1}*SUB$			25.63^{***}	(2.088)		
$CR1_{t-1}*PAT$			46.84^{***}	(3.675)		
$CR2_{t-1}*NO$			11.95^{***}	(2.870)		
$CR2_{t-1}*SUB$			22.45^{***}	(1.862)		
$CR2_{t-1}*PAT$			38.12^{***}	(4.337)		
$CR3_{t-1}*NO$			6.231^{**}	(2.581)		
$CR3_{t-1}*SUB$			23.79^{***}	(3.652)		
$CR3_{t-1}*PAT$			31.36^{***}	(2.896)		
round1_15**NO*					3.39^{**}	(1.511)
round1_15**SUB*					-6.004^{***}	(1.917)
round1_15**PAT*					1.286	(1.838)
N	2610		2610		2610	
R^2	0.211		0.218		0.215	

Standard errors are given in parentheses and are corrected for matching group clusters. As we drop the constant in the estimated models, the reported R^2 is taken from the (analogous) models as presented in Table A3.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The above OLS regression measures the effects of the tested parameters in each treatment (i.e., whether a parameter has an influence on a firm's investment level for each treatment separately). For a comparison of effects between treatments (i.e., whether a parameter has a stronger influence in one treatment than in the other) see

OLS regression results given in Table A3 in the Appendix. As the reference treatment we drop the treatment dummy ‘*SUB*’. Table A3 clearly indicates that the positive effect of firm *i*’s successful innovation (compared to no success) on investment levels is significantly stronger in *PAT* than in *SUB* and significantly weaker in *NO* than in *SUB* (see models (1) and (3)). Moreover, the positive effect of a successful cost reduction on the investment level if firm *i* is the exclusive innovator or if firm *i* and one other firm successfully innovate is as well in *PAT* significantly higher and in *NO* significantly lower than in *SUB* (see model (2)).

4.1.2 Individual investment decisions

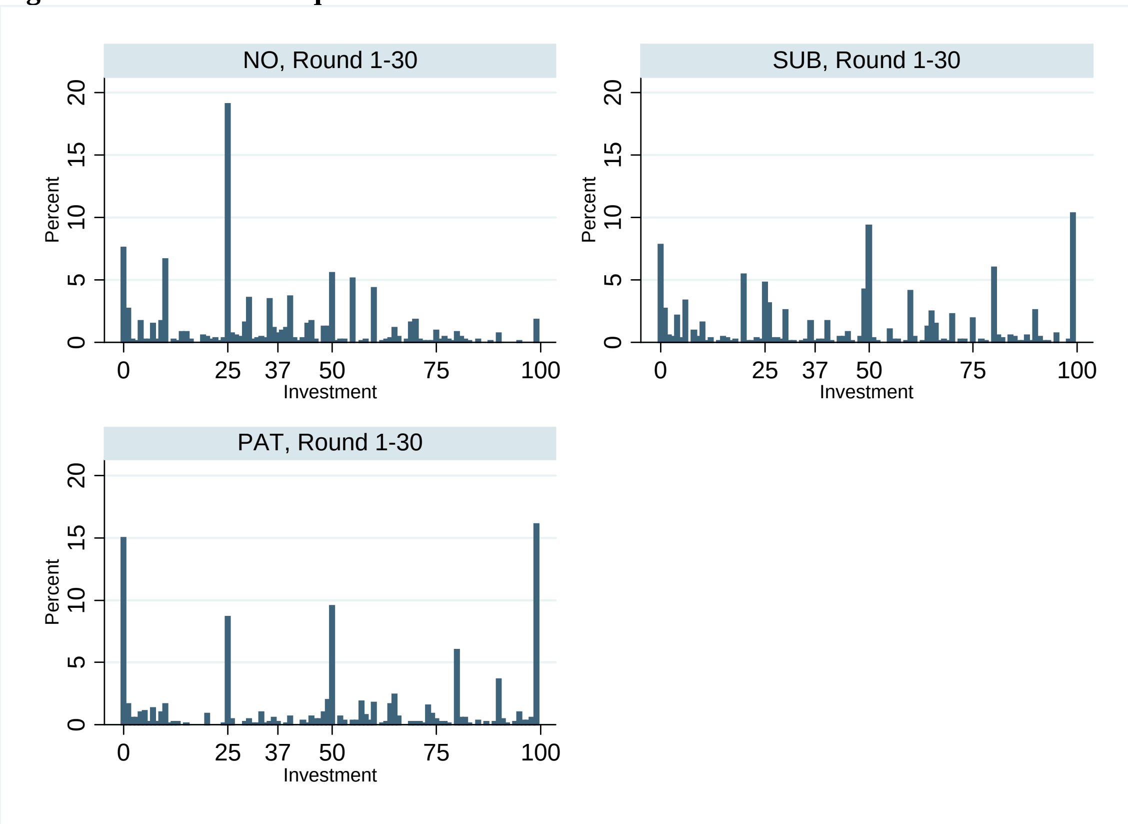
In the previous sections we focused on symmetric Nash equilibrium R&D investment strategies, which specifically imply that each firm always chooses a discrete investment level of 25 in *NO* and 37 in *SUB* and *PAT*. However, the actual investment levels are very diverse: Figure 2 specifies the frequencies of the chosen investment levels for each treatment.[29] Obviously, in the baseline treatment without policy instruments the predominant investment level is consistent with the symmetric Nash equilibrium investment level of 25 (this level is chosen in 19.11% of cases). Yet keeping the endowment and investing zero is the second most chosen behavior in this treatment. On the contrary, in the two treatments with policy instruments the Nash equilibrium of 37 is almost never chosen (in less than 1% of the cases). In the *PAT* treatment the most frequently chosen investment levels are zero (15%) and the maximum of 99 (16.11%). This behavior obeys kind of an ‘all-or-none law’: a subject either invests his complete endowment trying to achieve low costs (and thus a possible competitive advantage in the two market periods) or a subject decides on retaining his endowment and not trying at all to reduce his costs for the market stage. A smaller percentage of investments of 9.56% is set equal to the intermediate level of 50. In the *SUB* treatment the most chosen investment levels 0, 50 and 99 are more uniformly distributed (7.78%; 9.33%; 10.33%). Investing 99 points is the most frequently chosen strategy in both treatments with policy instruments,[30] whereas investing the maximum amount plays nearly no role in the baseline treatment. To examine these observed frequencies further, we consider

[29] Individual investment behavior over rounds is given in Figure A1 in the Appendix. A small fraction of subjects sticks to a certain investment level (or adjusts the investment level only slightly over rounds). Investment levels remaining constant over rounds are most frequently observed in the *PAT* treatment.

[30] The accumulation of the maximum investment level in *SUB* and *PAT* might be a further indication that the introduction of either policy instrument provides stronger incentives to invest in R&D.

asymmetric equilibria in the following. Table 6 summarizes discrete symmetric and asymmetric Nash equilibrium R&D investment levels for our experimental parameters. Note that the discrete parameterization gives raise to asymmetric equilibria. In the continuous case there exists only a unique symmetric equilibrium investment level in *NO*, and a symmetric and three asymmetric equilibria in *SUB* and *PAT* (compare footnote 18).

Figure 2: Investment frequencies



To understand the frequencies shown in Figure 2, it might be helpful to consider asymmetric Nash equilibria (see Table 6). In all treatments there exist three asymmetric Nash equilibria in which two firms choose 0 and one firm chooses 99. This is consistent with the observed investment levels of 0 and 99. However, note that the predicted asymmetric equilibria of (0, 0, 99) fail to explain (i) why 99 is chosen even more often than the minimum level of zero in *SUB* and *PAT*, and (ii) why 0 and 99 are less frequently chosen in *NO* than in *SUB* and *PAT*. The first observation might hint at a possible coordination failure. The asymmetric equilibria add a substantial coordination problem to the subjects' decision task.[31] The second observation that 0 and 99 are less frequently chosen in *NO* than in *SUB* and *PAT* may be explained by additional asymmetric investment levels which exclusively occur in *NO*: In *NO* the number of discrete asymmetric Nash equilibria is highest (in *SUB* and *PAT* there exist – besides the symmetric equilibrium – only the asymmetric equilibria in which one firm invests all and the other two firms invest nothing (0,0,99)). In *NO* there are in addition asymmetric Nash equilibria consisting of R&D investment levels from the interval [20, 21,..., 30]. Note that although in *NO* the number of discrete asymmetric Nash equilibria is highest, *NO* is nevertheless the treatment in which behavior is most consistent with the symmetric Nash equilibrium. This might be due to the fact that the additional asymmetric investment levels are oscillating around the symmetric equilibrium investment level of 25. Hence, it seems that asymmetric Nash equilibria can contribute to explain some of our data.[32]

Table 6: Discrete symmetric and asymmetric Nash equilibrium investment levels

Treatment		Investment decision r_i	r_j	r_k
NO	*Symmetric*	25	25	25
	Asymmetric	All combinations of investment levels [20,…,30] that add up to 75, without (25,25,25)		
		0	0	99
SUB	*Symmetric*	37	37	37
	Asymmetric	0	0	99
PAT	*Symmetric*	37	37	37
	Asymmetric	0	0	99

All asymmetric equilibria are given in Table A1 in the Appendix.

We also examine the dynamics of investment behavior in order to analyze whether there is a convergence to equilibrium levels over rounds. Therefore we consider investment behavior of the first round as well as investment behavior of the first third, second third and last third of rounds separately (Figures 3 – 5). Strikingly, investment

[31] However, there seems to be evidence that at least some subjects are aware of this coordination problem, because we observe subjects 'jumping' from very low investment levels to very high investment levels and vice versa especially in the *SUB* treatment (cf. Figure A1 in the Appendix). In general, investments are strategic substitutes since a subject has an incentive to decrease his own investment if a rival increases his investment and vice versa (see comparative statics in the Mathematical Appendix D4).

[32] Besides behavior that is consistent with asymmetric equilibria, we observe 'local maxima' in all three treatments, which occur in 5-scale increments. By local maxima we mean investment levels which are chosen more frequently compared to investment levels slightly below and slightly above these maxima (e.g. in the range from 50 to 60 investments of 50, 55 and 60 are chosen in more cases than intermediate investment levels). This may be explained by the prominence level of numbers (see Albers (2001)) as these investment level increments seem to create focal points.

levels of 25 (which is no equilibrium strategy in *SUB* and *PAT*) and 50 are chosen frequently (50 is even the most chosen investment level in *NO* and *PAT* in the first round). Possible explanations for this observation might be that those investment levels are prominent numbers and, moreover, that an investment of 25 gives a 50% chance of a successful innovation, which might also create a focal point. However, note that an investment level of 25 is chosen much more frequently in *NO* – where it is the symmetric equilibrium level. Thus, at least a part of this percentage in *NO* seems to be driven by equilibrium investment behavior. Furthermore, the fraction of the chosen symmetric Nash equilibrium level of 25 in *NO* remains constant from the first third till the last third (although it is lower in the first round in which the most chosen investment level is 50). In general, in all treatments non-equilibrium investment levels decrease over rounds and there seems to be a tendency to converge to the asymmetric equilibria (0, 0, 99). Especially the fraction of zero investment, which belongs to an asymmetric equilibrium strategy, increases. Specifically, in *SUB* non-equilibrium levels (in particular choosing 50) decrease over rounds converging to the extreme points 0 and 99 and also the *PAT* treatment clearly indicates that the extreme investment levels 0 and 99 are chosen more frequently in later rounds (non-equilibrium levels decrease in favor of 0 and 99).

Figure 3: Dynamic view on investment level choices – *NO*

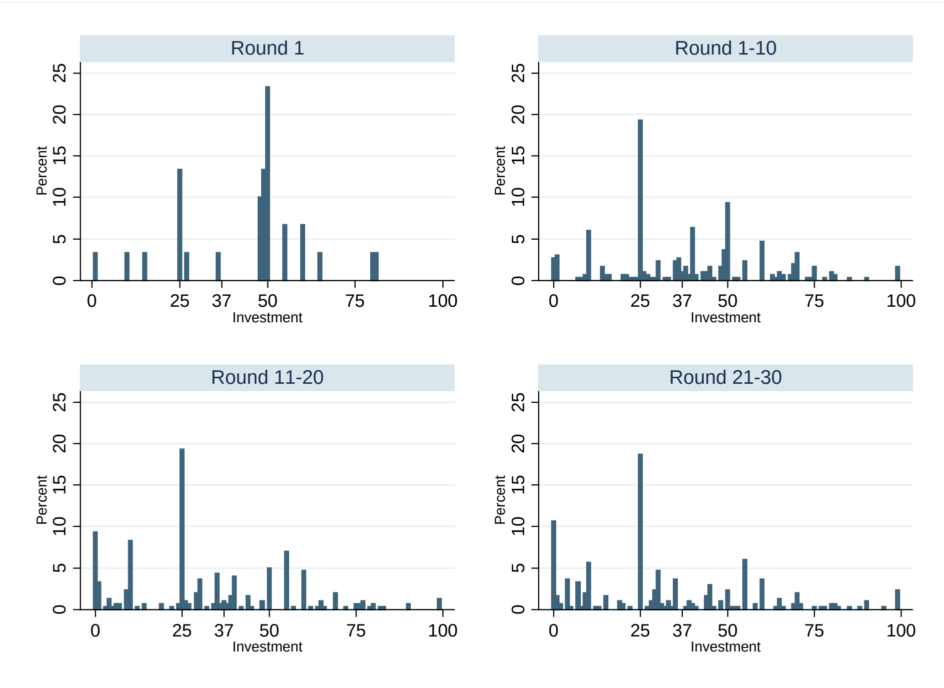


Figure 4: Dynamic view on investment level choices – *SUB*

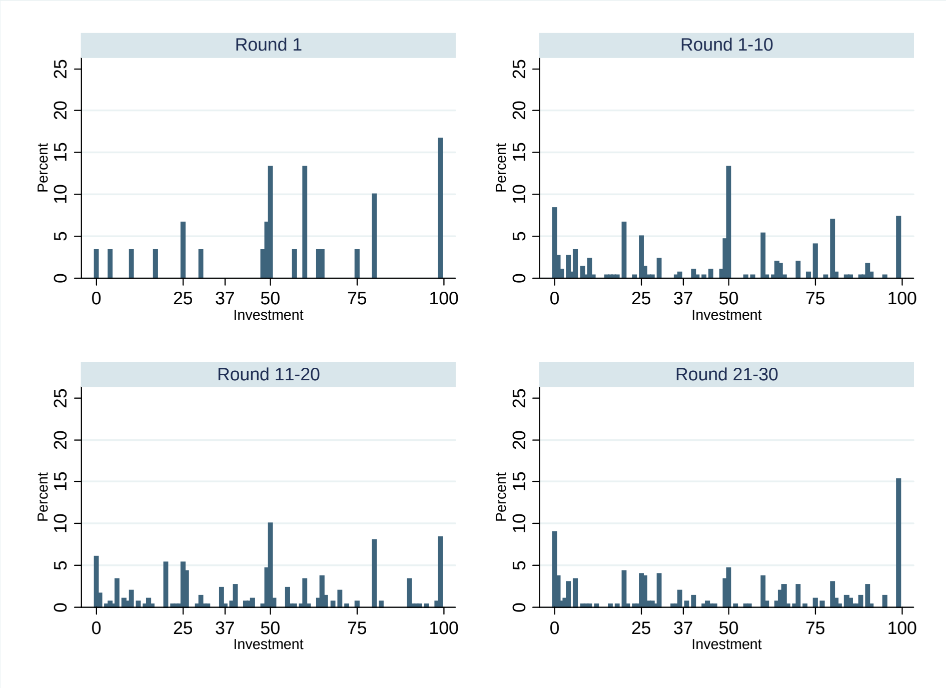
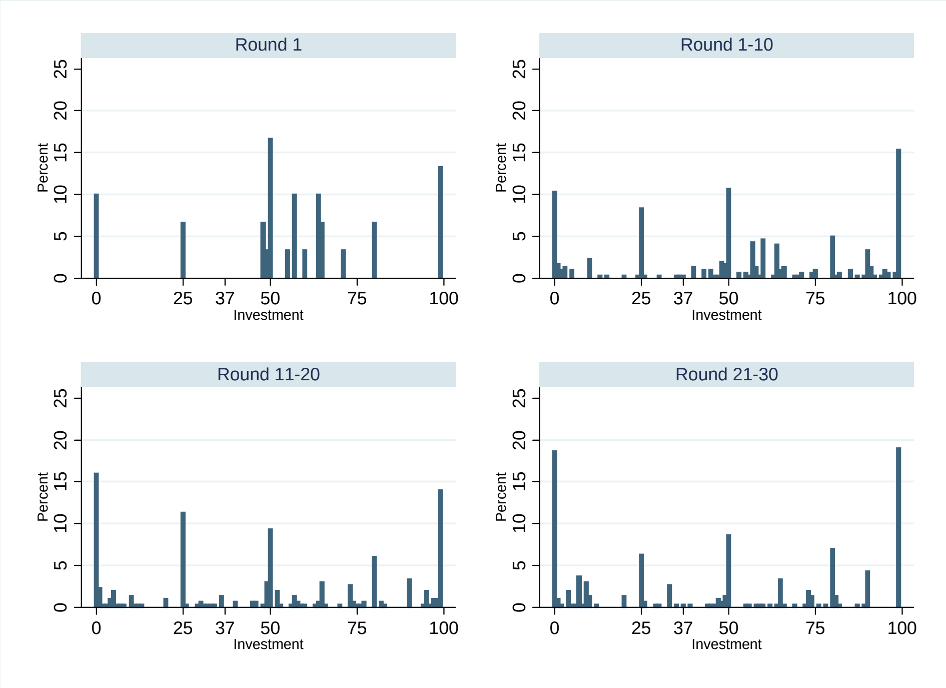


Figure 5: Dynamic view on investment level choices – *PAT*



***ER Investment levels*:**

Result 1: *Concerning the investment levels the experimental data show the following:*

- *The introduction of each policy instrument (SUB and PAT) significantly increases the investment level compared to no governmental R&D intervention (by 35.79%*

and 45.62% compared to a theoretical increase of 48.64%), which is in favor of Hypothesis 1.

- *As compared to the Nash predictions, firms overinvest in R&D with and without R&D policy instruments.*

Result 2: *The dynamics of R&D investment decisions are very similar between treatments: previously successful innovation has a positive effect on current investment decisions independent of other firms' success. Moreover, investment levels increase strongest if a firm was the exclusive innovator in the previous round and if patent protection is implemented.*

Result 3: *In NO, the modal R&D investment level is indeed the predicted level of 25, whereas the modal level of 99 in SUB and PAT is different from the predicted 37. The second and third most frequently chosen levels are 0 and an intermediate level of 50 in PAT, and 50 and 0 in SUB. These observations might be (partly) explained by asymmetric equilibria. Investment levels tend to converge to the asymmetric equilibrium levels of 0 and 99 over rounds.*

4.2 Cost structure, prices, and profits

4.2.1 Cost structure

The cost structure in the first Bertrand market period (i.e., the number of firms facing low costs of 100 and the number of firms facing high costs of 500) is determined by the number of successful innovations. The cost structure in the second Bertrand market period depends on the cost structure of the first market as well as on the chosen policy instrument. Table 7 gives observed frequencies of the different cost structures in the two Bertrand market periods (and as a benchmark predicted frequencies in case of symmetric discrete equilibrium investment levels). Only in the *PAT* treatment the innovating firms are protected against imitation. Thus, in this treatment the number of low cost firms does not change in the 2*nd* market. In the other two treatments however, in the second market period there are either three firms with high costs (if in the first market period there was no low cost firm in the market) or three firms with low costs (in all other cases). Markets with two or three low cost firms occur more often in *SUB* and *PAT* than in *NO* after the investment stage. Moreover, we observe the extreme case of three high cost firms (see column 'zero' in the 1*st* period) twice as often in the baseline treatment as in *SUB* and *PAT*. The higher percentage of successfully innovating firms in a market is a result of the higher investment levels in treatments with policy instruments.

Table 7 reveals only slight differences in observed proportions of cost structures as compared to those predicted by symmetric R&D investment strategies.[33] Specifically, predicted proportions are always higher than observed proportions if there is no low cost firm in the market in all three treatments, whereas the chances of two or three low cost firms in a market are typically higher than predicted.[34] This observation can be explained by the observed overinvestment in all three treatments. The observed frequency of a sole low cost firm is smaller than predicted in *NO* and *SUB*, but higher in *PAT*. Theoretically, *SUB* and *PAT* should result in identical frequencies of cost structures in the first market. Note however, that in *SUB* more successful innovations occur than in *PAT* (the percentage of two and three low cost firms is higher and the percentage of no or one low cost firm is lower in *SUB*).

Table 7: Observed (predicted) cost structure in the Bertrand markets

Bertrand markets	Treatment	*Number of low cost firms 1st period*				
		Zero	*one*	*Two*	*Three*	*total*
1st	*NO*	11.67% (12.5%)	32.33% (37.5%)	41.33% (37.5%)	14.67% (12.5%)	100% (100%)
	SUB	4.67% (6.01%)	24.00% (28.00%)	48.67% (43.48%)	22.67% (22.51%)	100% (100%)
	PAT	5.67% (6.01%)	29.67% (28.00%)	46.33% (43.48%)	18.33% (22.51%)	100% (100%)
		Number of low cost firms 2nd period				
		Zero	*one*	*Two*	*Three*	*total*
2nd	*NO*	11.67% (12.5%)	0% (0%)	0% (0%)	88.33% (87.50%)	100% (100%)
	SUB	4.67% (6.01%)	0% (0%)	0% (0%)	95.3% (93.99%)	100% (100%)
	PAT	5.67% (6.01%)	29.67% (28.00%)	46.33% (43.48%)	18.33% (22.51%)	100% (100%)

The number of low cost firms indicates how many of the three competing firms in each Bertrand market attain low cost of 100. Predicted cost structure taking discrete symmetric Nash equilibrium investment levels of 25 in *NO* and 37 in *SUB* and *PAT* are given in parentheses.

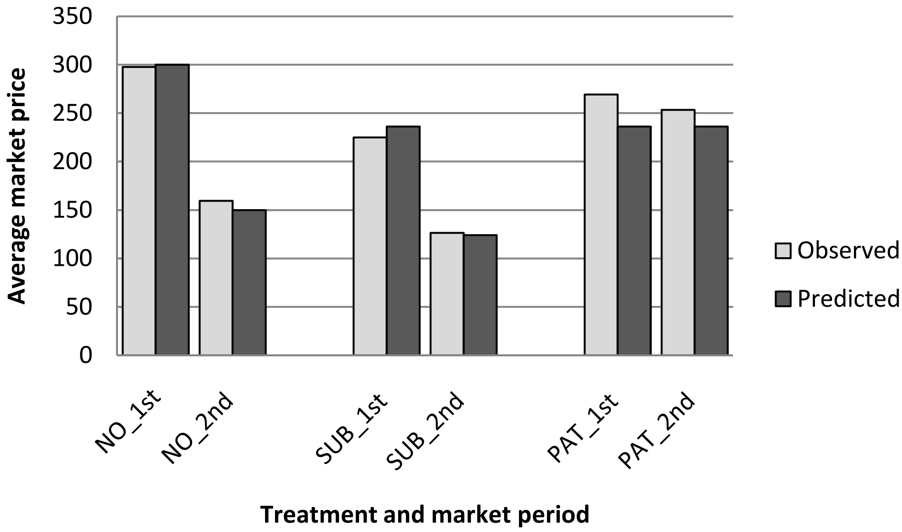
[33] This is a surprising result. Although the majority of individual behavior is not consistent with the discrete symmetric equilibrium investment level, on average similar market structures result as predicted by the symmetric Nash equilibrium.

[34] However, Chi-square goodness-of-fit tests yield no significant differences on the 10%-level in observed and predicted frequencies for all three treatments in the first market period (χ^2 - values are given by 4.60, 4.48 and 3.24 in *NO*, *SUB* and *PAT*). It is not possible to calculate Chi-square tests for the second period as there are parameter values equaling zero in *NO* and *SUB*.

4.2.2 Prices and Mark-ups

Figure 6 depicts the average market price (i.e., the lowest price $p_{i,t}^{\min} = \min[p_{1,t}, p_{2,t}, p_{3,t}]$ set in each market) for the three treatments for both market periods. Obviously, observed market prices in the experiment are on average close to those theoretically predicted (if subjects choose discrete symmetric equilibrium investment levels and equilibrium market prices).

Figure 6: Average Market Price



The average observed (predicted) market price was derived by taking the observed (predicted) frequency of each cost structure after the investment stage (see Table 7) and multiplying these probabilities with the observed (predicted) average lowest prices of each cost structure. Note that the average market price thus includes all different cost structures.

Under Bertrand competition market prices are mainly driven by the underlying cost structure. Therefore, Table 8 presents the average of actual market prices in the 1*st* and 2*nd* Bertrand markets for each cost structure separately.[35] Again, in all three treatments average market prices are close to those theoretically predicted. If there are only high cost firms in the market (column 1) prices are slightly above 500 in all three treatments (in the 1*st* market slightly higher prices are set than in the 2*nd* market). If there is one low cost firm in the first market (column 2), prices are set again close to

[35] We proceed in the following way: After the investment stage four different states of nature may occur - the numbers of successful innovations before Bertrand market starts are either zero, one, two or three. We calculate for these four different cases the average of *lowest* prices over all rounds separately for the 1*st* and for the 2*nd* market. Note that the labeling 'Number of innovating firms' alludes only to the number of low cost firms at the beginning of the first market period, not to the second market period (where number of low-cost firms might differ due to imitation).

those theoretically predicted. One low cost firm in the first market means three low cost firms in the second market due to imitation in *NO* and *SUB*. Thus, prices drop close to 100 except for the *PAT* treatment, where innovation is protected (prices stick to nearly 499). In case of two successfully innovating firms market prices in the first market period are between 127.77 and 149.20 on average, depending on the treatment (column 3). This cost structure implies that there are in the second market three low cost firms again in *NO* and *SUB* and still two low cost firms in *PAT*. The last column gives the average lowest prices if there are three low cost firms in the 1*st* and thus also three low cost firms in the 2*nd* market in all three treatments. In case of zero, two as well as three low cost firms prices are lower in the 2*nd* than in the 1*st* market period. Moreover, prices are higher than theoretically predicted in all cases, except the case that one firm has low costs and the other two firms have high costs.[36] Figure A2 in the Appendix depicts average lowest prices for each cost structure in the 1*st* and 2*nd* Bertrand markets for each round. The figure shows that average market prices converge to the Bertrand equilibrium prices over rounds as well as over market periods: First, average prices in general converge to the equilibrium price over rounds and second, prices in the 2*nd* market are nearly always set closer to the equilibrium price than those of the corresponding 1*st* market.

Table 8: Average of lowest prices observed (predicted) in the Bertrand markets

Bertrand markets	Treatment	*Number of innovating firms*			
		Zero	*One*	*two*	*three*
1st	*NO*	508.37 (500)	494.37 (499)	146.13 (100)	124.14 (100)
	SUB	507.36 (500)	473.00 (499)	127.77 (100)	112.69 (100)
	PAT	519.29 (500)	493.88 (499)	149.20 (100)	131.36 (100)
2nd	*NO*	504.66 (500)	113.39 (100)	114.23 (100)	113.55 (100)
	SUB	504.93 (500)	107.26 (100)	108.77 (100)	106.12 (100)
	PAT	504.53 (500)	494.99 (499)	124.48 (100)	111.13 (100)

The number of innovating firms indicates the successfully innovating firms after the investment stage (i.e., low cost firms in the first market period), but does not refer to imitating firms in the second market period. Note that in case of a sole low cost firm the discrete equilibrium price is 499, otherwise the sole innovator runs the risk of sharing the demand and decreasing his profits considerably.

[36] Slightly higher prices in these cases might be explained by the fact that in the discrete case firms can achieve positive profits even if they are not the only innovating firm with low costs. Note that in the discrete case 501(and 101) are also equilibrium prices for zero (two and three) innovating firms.

With the average lowest price (market price) for each cost structure given by Table 8 we can derive the expected mark-ups of firms depicted in Table A4 [37]. The finding that prices and thus mark-ups are higher if there are only two low cost firms in the market is consistent with what has been observed in previous Bertrand market experiments: E.g. Dufwenberg and Gneezy (2000) find that the number of competing firms with identical marginal costs influences the fierceness of competition in a Bertrand oligopoly experiment. Their data provide evidence that prices converge towards the theoretical prediction when there are groups of three or four competitors, whereas prices are much higher than predicted when only two competitors are matched. Hence, these observations can be explained by the influence of market concentration (of firms with identical low costs) on price setting. For a detailed analysis of the mark-ups please refer to Appendix A3.

4.2.3 Profits

This subsection surveys the profits of the firms. We differ between profits achieved solely at the market stage and profits over both stages of the game: *Market profits* (given separately for the *first period*, *second period*, and *both periods*) refer to the actually realized profit per firm at the market stage and *round profits* defined as *endowment* - *investment cost* + *market profits over both periods* give profits over both stages (including the investment and the market stage). Table 9 gives average market profits over rounds for both periods separately and in sum.[38]

For each specific cost structure after the investment stage $\pi_i(c_{i,1}^H)$ and $\pi_i(c_{i,1}^L)$ denote firm *i*'s profits depending on its marginal costs (e.g. $c_{i,1}^H$ refers to firm *i* starting with high marginal costs after the investment stage in market period t=1). Note that in *NO* and *SUB* in case of one and two low cost firms after the investment stage all three firms face low costs in the 2*nd* market period due to imitation. Table 9 summarizes average total market profits per firm for all cost structures as well as market profits per firm

[37] Note that only those firms benefit from the mark-up who set the lowest price in their market.

[38] Note that there is a difference between mark-ups and market profits. Mark-up refers to the potential profit margin in a market with a specific cost structure, thus measuring a firm's profit margin if a single firm sets the lowest price. Since mark-ups present the potential profit margin they can be interpreted as incentives to innovate in order to enable a firm to set the lowest price in the market. Average market profits, however, refer to the sum of actually realized profits in a market *divided by the number* of firms, thus measuring the average profit per firm (including also the 'losing' firms). Hence, average market profits can be seen as the expected profit a firm could obtain ex ante.

separately for low and high cost firms if both types share a market. Total market profits give the average profit of a market per firm for each cost structure (which naturally equals profits of solely high (low) cost firms in zero (three)). Concentrating on average total market profits over both market periods (which can be interpreted as a firm's expected profit at the market stage before it gets to know if it successfully innovates or not) it holds again for each possible cost structure that firms benefit most from *PAT* and achieve lowest profits in *SUB* as theoretically predicted (for this matter refer also to the following subsection).

Table 9: Average market profits per high and low cost firms

Treatment	*Number of innovating firms*							
	Zero	*One*			*Two*			*three*
	$\pi_i(c^H_{i,1})$ = *total*	$\pi_i(c^L_{i,1})$	$\pi_i(c^H_{i,1})$	*Total*	$\pi_i(c^L_{i,1})$	$\pi_i(c^H_{i,1})$	*Total*	$\pi_i(c^L_{i,1})$ = *total*
NO_1st	2.79	390.25	0.00	130.08	21.45	0.00	14.30	8.05
SUB_1st	2.45	367.44	0.00	122.48	13.89	0.00	9.26	4.23
PAT_1st	6.43	389.38	0.00	129.79	24.60	0.00	16.40	10.45
NO_2nd	1.55	5.49	3.95	4.46	3.99	6.25	4.74	4.52
SUB_2nd	1.64	1.76	2.75	2.42	2.33	4.10	2.92	2.04
PAT_2nd	1.51	389.93	0.28	130.16	12.24	0.00	8.16	3.71
NO_both	4.34	395.74	3.95	134.55	25.44	6.25	19.05	12.56
SUB_both	4.10	369.21	2.75	124.90	16.22	4.10	12.18	6.27
PAT_both	7.94	779.31	0.28	259.96	36.84	0.00	24.56	14.16

Now we take a look on firms' average round profits including the investment stage. We can interpret the average round profits as the expected profits a firm can gain in general in a specific treatment per round (regardless of a specific cost structure). As round profits measure the ex ante expected profit, they indicate which treatment is most profitable for firms. Table 10 summarizes the average (predicted) profits of all firms over all rounds for the three treatments. Note that round profits (observed as well as predicted) are smallest in *SUB*, however profits do not differ significantly between treatments. A Kruskal-Wallis test as well as pair-wise Mann-Whitney-U tests reveal no significant differences in average profits across treatments using matching groups.[39]

[39] Kruskal-Wallis test yields p=0.171 and pair-wise one-tailed Mann-Whitney-U tests yield p=0.274 (*NO-SUB*), p=0.075 (*NO-PAT*) and p=0.075 (*SUB-PAT*).

Table 10: Average observed and predicted round profits

Round profits	*NO*	*SUB*	*PAT*
Observed	119.25 (119.92)	114.11 (102.85)	141.34 (226.07)
Predicted	124.88	118.74	137.48

Standard deviations are given in parentheses. To calculate predicted levels we use the discrete symmetric equilibrium (25 in *NO* and 37 in *SUB* and *PAT*) and $\Delta c = 399$.

ER Cost structures, prices and profits:

Result 4: *The predicted and observed proportions of market structures show only slight differences.*

Result 5: *Average market prices converge to predicted Bertrand market prices (over rounds as well as over subsequent market periods). This results in mark-ups (and thus the incentive to invest in R&D) being highest in PAT (over the two market periods). Observed mark-ups of a sole low cost firm are somewhat lower than in Nash equilibrium and mark-ups are somewhat higher when there are zero, two, or three low cost firms.*

Result 6: *Firms' profits are highest in PAT and lowest in SUB (although we find no significant difference), which confirms the tendency of firms' interest as stated in Hypothesis 3.*

4.3 Welfare effects

In this subsection, we examine the effects of subsidies and patents on welfare at the society level and at the level of interest groups (i.e., consumers, firms,[40] and government). For each treatment Table 11 gives observed and predicted (in parentheses) added welfare as compared to a benchmark situation in which all firms make zero-R&D investments. There are three main observations: First, in comparison to zero-investments in R&D, total social welfare (as well as total consumer surplus and total firms' profits) increases intensely if firms invest in R&D with and without R&D instruments (which is shown by the fact that all added values in all treatments are positive). Second, if firms invest in R&D, added social welfare (*NO*: 600.56; *SUB*:

[40] Note that we refrain from including the firms' experimental endowment of 100 in the producer rent in contrast to round profits presented in Table 10 in the last subsection. Here we use instead the formula of rents given in Appendix A1.

620.88; and *PAT*: 601.38) does not differ significantly between our treatments,[41] which implies that added social welfare cannot be enhanced by the introduction of policy instruments. However, subsidies and patents have very different consequences for the distribution of welfare within society. As compared to the situation without R&D policy (*NO*), on the one hand subsidies increase consumer welfare by 105.95 points and on the other hand they reduce industry profits by 15.42 points and government budget by 70.23 points. In contrast, patents decrease consumer welfare by 65.47 points, leave the government budget unaffected, and increase firms' profits by 66.29 points.[42] Third, observed added social welfare and added welfare shares are lower than the theoretically predicted values (besides consumer rent in *SUB* and producer rent in *PAT*),[43] which can be explained by the overinvestment mentioned above. This result implies that those interest groups which are anyway privileged by a policy instrument (consumers in *SUB* and firms in *PAT*), realize even higher rents than predicted at the expense of the already disadvantaged group.

However, it remains the problematical question what practical implications can actually be derived. Our welfare results have to be interpreted with caution as our model and experimental setting are subject to some limitations which deserve mention: We neglected the funding of subsidies (for instance, in our model government budget is not linked to consumers by tax) and further patent costs (which occur due to the possible monopoly position of an innovating firm with patent protection: e.g. future welfare might decrease as firms' incentives decrease to invest in future R&D projects). For these reasons a complete welfare analysis is beyond the scope of this paper. But even in our simplified framework it can be shown that the decisions of whether and which R&D policy should be introduced seem to be sensitive to the political process of interests.

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[41] Using added welfare per matching group a Kruskal-Wallis test yields $p>0.5$ and two-tailed Mann-Whitney-U tests $p>0.1$ for each comparison. Note however, that a replication of the experiment would be reasonable in order to check the robustness of results by getting more independent observations.

[42] The increase in consumer rent if *SUB* is introduced compared to *NO* is significant at the 1%-level (one-tailed Mann-Whitney-U test). All other comparisons do not yield significant differences. This result might be partly driven by a small sample size of only 5 independent observations.

[43] CR in *SUB* is higher than expected, because more successful innovations take place than theoretically predicted (compare Table 6: theoretically *SUB* and *PAT* should provide identical cost structures (due to the Nash equilibrium of 37 in both treatments), however more successful innovations occur in *SUB* for two and three firms). In *PAT* we observe a higher than predicted frequency of one low cost firm in the market which might explain the higher PR.

Table 11: Average welfare effects

Treatment	Added welfare – observed (predicted)			
	Social welfare	Consumers	Producers	Government
NO	600.56 (623.25)	542.83 (548.63)	57.74 (74.63)	0.00 (0.00)
SUB	620.88 (639.03)	648.78 (638.31)	42.32 (56.23)	-70.23 (-55.50)
PAT	601.38 (639.03)	477.36 (526.58)	124.03 (112.45)	0.00 (0.00)

To calculate predicted levels we use the discrete symmetric equilibrium (25 in *NO* and 37 in *SUB* and *PAT*) and $\Delta c = 399$.

ER Welfare effects:

Result 7: *R&D subsidies and patents do not increase social welfare significantly (due to overinvestment), thus we question Hypothesis 2. However, we observe an (although not significant) tendency that both policy instruments cause redistribution within society. With subsidies, consumers gain welfare at the expense of industry profits and government budget. With patents, the industry increases profits at the expense of consumer welfare. These results seem to support Hypothesis 3.*

5. Conclusions

This paper investigates the performance of two prominent policy instruments used to enhance firms' investments in R&D: subsidies and patents. A successful R&D innovation entails lower marginal costs for the innovating firm. We use a two-stage stochastic R&D model with an investment stage followed by a Bertrand price competition stage with two market periods and derive equilibrium investments and prices for our experimental parameters. In equilibrium, both patents and subsidies induce the same amount of R&D investment, which is higher than the investment without governmental incentives. To test these theoretical predictions we run an experiment comparing a baseline treatment without any policy instrument with two treatments in which either subsidies are paid to investing firms or in which innovating firms are granted patent protection respectively. Our main finding at the investment stage is a significant increase in investment levels if a policy instrument is implemented. Thus, our experiment provides evidence that both instruments are effective in promoting investments in R&D.[44] However, we observe overinvestment in all three

[44] Theoretically both introducing a subsidy as well as patent protection should increase the investment level by the same amount compared to the situation in which no policy instrument is used. This is

treatments. This overinvestment might be on the one hand explained by asymmetric discrete equilibrium investment levels (especially those in which one firm invests the maximal amount and two other firms refrain from investing) and a simple coordination failure of the subjects. On the other hand, this result might be (also) due to the specific properties of a Bertrand market: a Bertrand market leads to 'aggressive' interaction among vigorous competitors. Competition in a Bertrand market is very strong in the sense that a firm makes zero-profits for sure if it does not become the only innovator in the market.[45] Maybe this all-or-none property tempts subjects into overinvesting in R&D.

Concerning the market stage we observe that although prices are set slightly above the marginal costs, they converge to the theoretically predicted Bertrand equilibrium prices both over rounds as well as over market periods. In general, note that despite the complex experimental setting (like implementing a two-stage game with endogenously determined profits), theory predicts outcomes *on average* quite well although individual investment behavior diverges from the predicted symmetric Nash equilibrium: e.g. market structures, average market prices, and average profits are close to the theoretically predicted levels.

Our data show that R&D investment increases added social welfare compared to no R&D investment, but also exposes that R&D subsidies as well as patents do not strongly affect social welfare compared to no policy instrument. This result is driven by the observed overinvestment discussed above. However, both policy instruments cause substantial redistribution within society. Firms fare better under patents than under no policy, the latter still yields higher profits than subsidies. The investigation of different 'interest groups' is important for policy analysis, because it reveals where support and opposition can be expected. Nevertheless, the described results should be interpreted carefully. Due to several limitations of our model an extensive welfare analysis is beyond the scope of this paper. Limitations of our analysis are the following: we do not include funding of the instruments, i.e., taxes would change the consumer surplus, for

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supported by our experimental results as the investment level does not differ significantly across the treatments *SUB* and *PAT*.

[45] Expecting Bertrand competition at the second stage creates a kind of the-winner-takes-all situation at the investment stage. Patent race literature suggests that non-colluding firms invest excessively in R&D (for a seminal paper see Loury (1979)). Doraszelski (2008) shows that this result strongly hinges on the winner-takes-all assumption. If this assumption is relaxed and patent protection becomes less effective firms might even underinvest in R&D.

instance, nor do we take the costs of granting patent protection into account. Patents have two effects on social welfare: on the one hand they provide incentives to innovate in R&D, but on the other hand they might create monopolies. If a firm holds a monopoly position this could in turn inhibit near-term following innovations.[46] These intertemporal aspects are neglected in our static framework analysis. Thus, as it is shown by Bessen and Maskin (2006), patents may be desirable to encourage innovation in a static setting (e.g. in their static model a patent protection leads to higher profits of a firm undertaking R&D as well as to higher welfare), but they might actually inhibit complementary innovation in a sequential setting in which imitation might even become a spur to innovation. Scotchmer (1991) also notes that including positive externalities and intertemporal knowledge spillovers, which early innovators confer on later innovators, poses new problems for the optimal design of patent law. Furthermore, our model lacks R&D coordination and cooperation (like cross-licensing agreements and joint ventures), which is very common in R&D intensive markets (compare e.g. Morasch (1995)). All these factors might have an essential influence on the impact of policy instruments on R&D investment and their successful implementation and should be investigated in future research.

Hence, further research is to be done on the robustness of our results concerning the effects of the policy instruments on investment behavior. Of course, our results cannot yield conclusive evidence for policy implications as we simplified the model a lot. However, our experiment is a first step and its insights might contribute to a broader research agenda on R&D investment promoting policy instruments: Our findings suggest that the tested policy instruments serve the purpose of rising investments and that the choice of an appropriate instrument depends on the political process of interests.

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[46] Note however, that this effect is alleviated by our design as it is possible that more than one firm successfully innovates. Therefore, patent protection in our experiment does not automatically imply monopoly power of an innovating firm.

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Appendix

Written instructions (translation from German)

Welcome and thank you very much for participating in this experiment. You receive 2.50 € for participating. Depending on your and other participants' decisions you can earn additional money. You collect points during the experiment with **300 points equaling 1 €**. At the end of the experiment your accumulated points will be converted into € and together with the 2.50 € paid out to you in cash. Payoffs remain *anonymous*. During the whole experiment, starting now, communication with other participants is strictly forbidden. If you have a question, please raise your hand. An experimenter will come to your place and answer your questions.

The experiment

The experiment consists of **30 rounds**. At the beginning of *each* round all participants are randomly divided into groups of 3 participants, i.e., the composition of your group changes in each round. In the following we refer to the 3 participants of your group as firm 1, 2, and 3. Your firm number is randomly drawn anew in each round. You do not interact with other groups in a respective round. Your identity is not revealed at any time before, during or after the experiment.

At the beginning of *each* round each participant receives an **endowment of 100 points** which is credited your personal account of points.

Each round consists of 2 phases ("phase 1" and "phase 2"). In addition phase 2 consists of two sub-phases ("phase 2A" and "phase 2B"). You make three decisions in each round, one in phase 1 and one in each of the phases 2A and 2B.

Phase 1 – 1st Decision

In phase 1 you and the two other firms in your group can make an investment. Each firm can influence the level of its costs in the *current round* by its investment. You can have either *high* or *low costs*. You invest by choosing an amount of points (integer) between 0 and 99 (0, 1, 2, …, 98, 99). Only you know your own investment (chosen points), it cannot be observed by any other firm. The same applies to the other firms.

PAT and NO:

Your investment induces **investment costs; they are equal to your investment (= chosen points) and will be subtracted from your endowment of 100 points.**

SUB:

Your investment induces **investment costs; they are equal to half of your investment (= chosen points) and will be subtracted from your endowment of 100 points.**

Your investment level determines the **probability** of having costs of **100 points** ("low costs") or of **500 points** ("high costs") in the *current* round. The higher your investment, the higher the probability that you have low costs (100 points). The same applies to the two other firms in your group.[47]

After you and the other two firms in your group made their investment decision, the computer separately draws a random number for *each* firm. The number is in the range of 0.1 and 100 whereby all numbers (0.1, 0.2, …, 99.8, 99.9, 100) have an equal chance to be drawn.

Two alternatives arise:

1) **Your random number is *smaller than or equal* to your probability of obtaining costs of 100 points:** In this case your costs amount to 100 points.
2) **Your random number is *higher than* your probability of obtaining costs of 100 points:** In this case your costs amount to 500 points.

The same applies to both other firms in your group. Thus, your costs only depend on your own investment level which yields the probability of obtaining certain costs and chance. Four different situations can arise: Either none, 1, 2 or all 3 firms of your group

[47] All participants received a table containing all possible investment levels, the according investment costs, and the resulting probabilities of obtaining costs of 100 or 500 points. The probabilities are calculated by the formula $\sqrt{i/100}$, *i* stands for the investment of one firm.

have low costs of 100 points (the rest of the firms in the group faces high costs of 500 points).

Phase 2A – 2nd Decision

At the beginning of phase 2A each firm within your group gets to know the costs of *all three* firms.

Each firm in your group is asked to choose a price between your own costs in phase 2A and 1000, i.e., a price either between 100, 101, 102, … 999, 1000, if you have low costs or between 500, 501, 502, .., 999, 1000, if you have high costs. Each firm only knows its own price and cannot observe the prices of the other two firms.

After all firms made their decisions, the computer identifies the *lowest* price within your group which all three firms get to know. There are three possibilities for your group in phase 2A with the according profits:

1) One firm in your group has chosen the lowest price:

The profit in points of the firm with the lowest price in phase 2A is calculated by *subtracting the costs of this firm in phase 2A from its chosen price*. Both firms with the higher prices receive *nothing* (0 points) in phase 2A, independent of their prices and costs in phase 2A.

2) Two firms in your group have chosen the same lowest price:

The profit in points of each firm with the same lowest price in phase 2A is calculated by *subtracting the costs from the chosen price and dividing the result by two*. The firm with the higher price receives *nothing* (0 points) in phase 2A, independent of its price and costs in phase 2A.

3) All three firms in your group have chosen the same price:

The profit in points of each firm in phase 2A is calculated by *subtracting the costs from the chosen price and dividing the result by three*.

If you have not chosen the lowest price of your group in phase 2A, you will not bear any costs. At the end of phase 2A your profit, which can either be positive or zero, is credited your personal account of points.

Phase 2B – 3rd Decision

PAT:

The 3rd decision is identical to the 2nd decision. **Each firm's costs have not changed compared to phase 2A.**

NO and SUB:

The 3rd decision just differs slightly from the 2nd decision in phase 2A. The decision procedure and the computation of profits in phase 2B are the same as in phase 2A. But compared to phase 2A there is an important difference: **In phase 2B the costs of all firms in one group are the same. The equal cost level in phase 2B corresponds to the lowest costs within the group in phase 2A.** The costs in phase 2B which are identical for all three firms in your group are announced within your group before you have to choose your price.

After a round (consisting of phase 1, phase 2A, and phase 2B) is finished you are informed again about your decisions and the results of this round. Afterwards the next round starts.

Profit per Round

	Profit per round =
Phase 1	endowment per round – investment costs in phase 1
Phase 2	+ profit in phase 2A
	+ profit in phase 2B

Probabilites and costs (for *NO* and *PAT*, in *SUB* investment costs are halved)

Your investment (chosen points)	Your investment costs	Probability of getting costs of 100 points in %	Probability of getting costs of 500 points in %
0	0	0,0	100,0
1	1	10,0	90,0
2	2	14,1	85,9
3	3	17,3	82,7
4	4	20,0	80,0
5	5	22,4	77,6
6	6	24,5	75,5
7	7	26,5	73,5
8	8	28,3	71,7
9	9	30,0	70,0
10	10	31,6	68,4
11	11	33,2	66,8
12	12	34,6	65,4
13	13	36,1	63,9
14	14	37,4	62,6
15	15	38,7	61,3
16	16	40,0	60,0
17	17	41,2	58,8
18	18	42,4	57,6
19	19	43,6	56,4
20	20	44,7	55,3
21	21	45,8	54,2
22	22	46,9	53,1
23	23	48,0	52,0
24	24	49,0	51,0
25	25	50,0	50,0
26	26	51,0	49,0
27	27	52,0	48,0
28	28	52,9	47,1
29	29	53,9	46,1
30	30	54,8	45,2
31	31	55,7	44,3
32	32	56,6	43,4
33	33	57,4	42,6
34	34	58,3	41,7
35	35	59,2	40,8
36	36	60,0	40,0
37	37	60,8	39,2
38	38	61,6	38,4
39	39	62,4	37,6
40	40	63,2	36,8
41	41	64,0	36,0
42	42	64,8	35,2
43	43	65,6	34,4
44	44	66,3	33,7
45	45	67,1	32,9
46	46	67,8	32,2
47	47	68,6	31,4
48	48	69,3	30,7
49	49	70,0	30,0
50	50	70,7	29,3
51	51	71,4	28,6
52	52	72,1	27,9
53	53	72,8	27,2
54	54	73,5	26,5
55	55	74,2	25,8
56	56	74,8	25,2
57	57	75,5	24,5
58	58	76,2	23,8
59	59	76,8	23,2

60	60	77,5	22,5
61	61	78,1	21,9
62	62	78,7	21,3
63	63	79,4	20,6
64	64	80,0	20,0
65	65	80,6	19,4
66	66	81,2	18,8
67	67	81,9	18,1
68	68	82,5	17,5
69	69	83,1	16,9
70	70	83,7	16,3
71	71	84,3	15,7
72	72	84,9	15,1
73	73	85,4	14,6
74	74	86,0	14,0
75	75	86,6	13,4
76	76	87,2	12,8
77	77	87,7	12,3
78	78	88,3	11,7
79	79	88,9	11,1
80	80	89,4	10,6
81	81	90,0	10,0
82	82	90,6	9,4
83	83	91,1	8,9
84	84	91,7	8,3
85	85	92,2	7,8
86	86	92,7	7,3
87	87	93,3	6,7
88	88	93,8	6,2
89	89	94,3	5,7
90	90	94,9	5,1
91	91	95,4	4,6
92	92	95,9	4,1
93	93	96,4	3,6
94	94	97,0	3,0
95	95	97,5	2,5
96	96	98,0	2,0
97	97	98,5	1,5
98	98	99,0	1,0
99	99	99,5	0,5

Mathematical Appendix

A1: Proofs

Proof of Proposition 1. Firm *i*'s expected total profit is given by

$$\pi_i^e(r_i, r_{-i}) = F(r_i)[1 - F(r_{-i})]^{n-1}(1+\theta)\Delta c - (1-\sigma)r_i,$$

where Δc gives *i*'s mark-up if it is the only low cost firm, which occurs with probability $F(r_i)[1 - F(r_{-i})]^{n-1}$ for 1+θ periods, and $(1-\sigma)r_i$ gives its R&D costs net of subsidy.[48]

Maximization of *i*'s expected total profit with respect to r_i yields

$$\frac{\partial \pi_i^e(r_i, r_{-i})}{\partial r_i} = f(r_i^*)[1 - F(r_{-i})]^{n-1}(1+\theta)\Delta c - (1-\sigma) \overset{!}{=} 0, \; \forall i.$$

Rearranging and assuming symmetry, i.e., r_i=r, $\forall i$, yields condition (1) as stated in our proposition:

$$f(r^*)[1 - F(r^*)]^{n-1}(1+\theta)\Delta c = 1 - \sigma,$$

where the left-hand and right-hand sides (henceforth *LHS* and *RHS*, respectively) give the expected marginal revenues MR^e, and marginal costs *MC*, of R&D investment, respectively. Comparative static analysis with each of the parameters $\Delta c, \theta$ and *n* is conducted like follows: We can rewrite condition (1) as $g(x, r(x)) = c$, where the *LHS* is a function of $x \in (\Delta c, \theta, n)$, which is the parameter of interest, and the investment level *r*. The *RHS* is a constant *c*. A marginal change in *x* leads to $\frac{dg}{dx} + \frac{dg}{dr}\frac{dr}{dx} = 0$. We are interested in $\frac{dr}{dx}$. Note that *LHS* is strictly decreasing in *r* ($\frac{dg}{dr} < 0$), because:

$$\frac{\partial LHS}{\partial r} = \left[f'(r)[1-F(r)]^{n-1} - (n-1)f(r)^2[1-F(r)]^{n-2}\right](1+\theta)\Delta c < 0 \quad \text{for } r \in (0,1)$$

with $f'(r)[1-F(r)]^{n-1} < 0$ and $(n-1)f(r)[1-F(r)]^{n-2} > 0$.

We derive for each specific *x* the derivative $\frac{dg}{dx}$ and thus can conclude whether $\frac{dr}{dx}$ must be increasing or decreasing. The procedure is analogous for the comparative statics with the parameter σ: Here we use the first order condition:

[48] A discount factor for the profits realized in subsequent rounds is neglected.

$f(r_i^*)[1-F(r_{-i})]^{n-1}(1+\theta)\Delta c-(1-\sigma)\overset{!}{=}0$, which can be rewritten as $g(x,r(x))=c$ again.

This analysis exposes the following influence of each parameter on the optimal investment level *r*:

- *Mark-ups:* For a change in Δc, $\frac{dg}{d\Delta c}>0$ and thus $\frac{dr}{d\Delta c}>0$ which implies that the equilibrium value of *r* increases if Δc increases.
- *Patent-protected market periods:* For a change in θ, $\frac{dg}{d\theta}>0$ and thus $\frac{dr}{d\theta}>0$ which implies that the equilibrium value of *r* increases if θ increases.
- *Subsidy:* For a change in σ, $\frac{dg}{d\sigma}>0$ and $\frac{dg}{dr}<0$ and thus $\frac{dr}{d\sigma}>0$ which implies that the equilibrium value of *r* increases if σ increases.
- *Number of firms:* For a change in *n*, $\frac{dg}{dn}<0$. Since $\frac{dg}{dr}<0$ it holds that $\frac{dr}{dn}<0$ which implies that the equilibrium value of *r* decreases if *n* increases.
- *Number of market periods:* Finally, the equilibrium value of *r* is independent of the number of market periods, *T*, because a firm can only receive strictly positive Nash equilibrium market profits if it is the only low cost firm. In our model the number of market periods in which this low cost firm can make such profits is entirely determined by the first period and the additional number of patent-protected market periods θ. However, *T* is the upper boundary of θ and thus may have an indirect effect on r^*. ■

Proof of Proposition 2. If firms choose the symmetric Nash equilibrium investment level, this yields the following implications for added welfare shares of different interest groups. Note first that the investment level *r* is strictly increasing in σ and θ as was shown in Proposition 1 ($\frac{dr}{d\sigma}>0$ and $\frac{dr}{d\theta}>0$). In the following we first present the derivatives of welfare shares with respect to σ, then with respect to θ. The added government rent is given by

$$GR(r^*,\sigma)=-nr^*\sigma \quad (2).$$

Hence, an increase in the subsidized proportion σ yields

$$\left.\frac{\partial GR(r^*,\sigma,\theta)}{\partial\sigma} = -n\sigma\frac{dr^*}{d\sigma} - nr^* < 0.\quad\right\}\ \text{transfer to PR}$$

Moreover, expected added consumer rent is given by[49]

$$\begin{aligned} CR^e(r^*,\theta,\sigma) &= nF(r^*)\left[1-F(r^*)\right]^{n-1}(T-1-\theta)\Delta c \\ &\quad + \sum_{k=2}^{n}\binom{n}{k}F(r^*)^k\left[1-F(r^*)\right]^{n-k}T\Delta c, \end{aligned}$$

which can be rewritten as

$$\begin{aligned} CR^e(r^*,\theta,\sigma) &= T\Delta c - \left[1-F(r^*)\right]^n T\Delta c \\ &\quad - nF(r^*)\left[1-F(r^*)\right]^{n-1}(1+\theta)\Delta c. \end{aligned} \tag{3}$$

This yields

$$\begin{aligned} \frac{\partial CR^e(r^*,\theta,\sigma)}{\partial\sigma} &= T\Delta cnf(r^*)\frac{dr^*}{d\sigma}\left[1-F(r^*)\right]^{n-1} \\ &\quad \left.- n(1+\theta)\Delta cf(r^*)\frac{dr^*}{d\sigma}\left[1-F(r^*)\right]^{n-2}\left[\left[1-F(r^*)\right]-(n-1)F(r^*)\right].\right\}\text{transfer to PR} \end{aligned}$$

Finally, expected added producer rent is given by

$$PR^e(r^*,\theta,\sigma) = nF(r^*)\left[1-F(r^*)\right]^{n-1}(1+\theta)\Delta c - n(1-\sigma)r^*. \tag{4}$$

Hence, we have

$$\begin{aligned} \frac{\partial PR^e(r^*,\theta,\sigma)}{\partial\sigma} &= \left. n(1+\theta)\Delta cf(r^*)\frac{dr^*}{d\sigma}\left[1-F(r^*)\right]^{n-2}\left[\left[1-F(r^*)\right]-(n-1)F(r^*)\right]\right\}\text{transfer from CR} \\ &\quad \left.+ nr^* + n\sigma\frac{dr^*}{d\sigma}\right\}\text{transfer from GR} \\ &\quad - n\frac{dr^*}{d\sigma}. \end{aligned}$$

Now we concentrate on an increase of the number of patent-protected periods θ. Concerning government rent this yields

$$\left.\frac{\partial GR(r^*,\sigma,\theta)}{\partial\theta} = -n\sigma\frac{dr^*}{d\theta} < 0.\quad\right\}\ \text{transfer to PR}$$

[49] For a derivation of the added consumer rent see the Mathematical Appendix D1.

Note that $\frac{\partial GR(r^*,\sigma,\theta)}{\partial\theta}=0$ if we consider 'pure' instruments (i.e., $\sigma=0$ if patent protection is on hand).

The derivatives of CR^e and PR^e with respect to θ are given by

$$\begin{aligned}\frac{\partial CR^e(r^*,\theta,\sigma)}{\partial\theta} &= T\Delta cnf(r^*)\frac{dr^*}{d\theta}\left[1-F(r^*)\right]^{n-1}\\ &\left.\begin{aligned}&-n(1+\theta)\Delta cf(r^*)\frac{dr^*}{d\theta}\left[1-F(r^*)\right]^{n-2}\left[\left[1-F(r^*)\right]-(n-1)F(r^*)\right]\\ &-n\Delta cF(r^*)\left[1-F(r^*)\right]^{n-1}\end{aligned}\right\}\text{transfer to PR}\end{aligned}$$

and

$$\begin{aligned}\frac{\partial PR^e(r^*,\theta,\sigma)}{\partial\theta} &= \left.\begin{aligned}&n(1+\theta)\Delta cf(r^*)\frac{dr^*}{d\theta}\left[1-F(r^*)\right]^{n-2}\left[\left[1-F(r^*)\right]-(n-1)F(r^*)\right]\\ &+n\Delta cF(r^*)\left[1-F(r^*)\right]^{n-1}\end{aligned}\right\}\text{transfer from CR}\\ &\left.+n\sigma\frac{dr^*}{d\theta}\right\}\text{transfer from GR}\\ &-n\frac{dr^*}{d\theta}.\end{aligned}$$

Then, our proposition holds, because there is rent shifting both between firms and government as well as between firms and consumers as indicated by curly brackets. More precisely, the first term of PR equals the second term of CR and the decrease of GR equals the increasing second term in PR. This is valid for an increase in the subsidized proportion as well as for an increase in the number of patent-protected periods. ■

A2: Derivations

D1: Derivation added consumer rent

Expected total consumer rent if firms invest is given by:

$$\begin{aligned}Total\ CR^e(r,\theta,\sigma) &= nF(r)\left[1-F(r)\right]^{n-1}(T-1-\theta)(\overline{p}-c^L)\\ &+nF(r)\left[1-F(r)\right]^{n-1}(1+\theta)(\overline{p}-c^H)\\ &+\sum_{k=2}^{n}\binom{n}{k}F(r)^k\left[1-F(r)\right]^{n-k}T(\overline{p}-c^L)\\ &+(1-F(r))^n(\overline{p}-c^H)T\end{aligned}\qquad\text{(A1)}$$

Total consumer rent if no firm invests in R&D (benchmark situation) is given by: $(\overline{p}-c^H)T$. Thus, subtracting the benchmark situation from the expected total CR results in an expected added consumer rent of:

$$\begin{aligned} CR^e(r,\theta,\sigma) = {} & nF(r)\left[1-F(r)\right]^{n-1}(T-1-\theta)(\overline{p}-c^L) \\ & + nF(r)\left[1-F(r)\right]^{n-1}(1+\theta)(\overline{p}-c^H) \\ & + \sum_{k=2}^{n}\binom{n}{k}F(r)^k\left[1-F(r)\right]^{n-k}T(\overline{p}-c^L) \\ & + (1-F(r))^n(\overline{p}-c^H)T \\ & - (\overline{p}-c^H)T \end{aligned} \quad \text{(A2)}$$

This expression can be rewritten as:

$$\begin{aligned} CR^e(r,\theta,\sigma) = {} & nF(r)\left[1-F(r)\right]^{n-1}(T-1-\theta)((\overline{p}-c^L)-(\overline{p}-c^H)) \\ & + nF(r)\left[1-F(r)\right]^{n-1}(1+\theta)((\overline{p}-c^H)-(\overline{p}-c^H)) \\ & + \sum_{k=2}^{n}\binom{n}{k}F(r)^k\left[1-F(r)\right]^{n-k}T((\overline{p}-c^L)-(\overline{p}-c^H)) \\ & + (1-F(r))^n((\overline{p}-c^H)-(\overline{p}-c^H))T \end{aligned}, \quad \text{(A3)}$$

because $(T-1-\theta)+(1+\theta)=T$ and $nF(r)\left[1-F(r)\right]^{n-1}+\sum_{k=2}^{n}\binom{n}{k}F(r)^k\left[1-F(r)\right]^{n-k}+(1-F(r))^n=1$. (A3) yields expected added consumer rent given in Proposition 2.

D2: Derivation of the optimal investment for our parameterization

The profit function of firm *i* (*i*={1, 2, 3}) with an endowment *B*=100 at the market stage in each of the 30 rounds is given by:

$$\pi_i(r_i,r_j,r_k)=(p-c^L)(1+\theta)F(r_i)(1-F(r_j))(1-F(r_k))-(1-\sigma)r_i+B$$

Taking the equilibrium price p=c^H, $F(r_i)=\frac{1}{10}r_i^{0.5}$, T=2, $\sigma=0.5$ and $\theta=1$ yield the following first order conditions (FOC):

FOC general:

$$\frac{\partial\pi_i(r_i,r_j,r_k)}{\partial r_i}=\frac{\frac{1}{20}(c^H-c^L)(1+\theta)(1-\frac{1}{10}r_j^{0.5})(1-\frac{1}{10}r_k^{0.5})}{r_i^{0.5}}-(1-\sigma)=0$$

FOC *NO* $(\sigma=0,\theta=0)$:

$$\frac{\partial \pi_i(r_i, r_j, r_k)}{\partial r_i} = \frac{\frac{1}{20}(c^H - c^L)(1 - \frac{1}{10} r_j^{0.5})(1 - \frac{1}{10} r_k^{0.5})}{r_i^{0.5}} - 1 = 0.$$

FOC *SUB* $(\sigma = 0.5, \theta = 0)$:

$$\frac{\partial \pi_i(r_i, r_j, r_k)}{\partial r_i} = \frac{\frac{1}{20}(c^H - c^L)(1 - \frac{1}{10} r_j^{0.5})(1 - \frac{1}{10} r_k^{0.5})}{r_i^{0.5}} - \frac{1}{2} = 0.$$

FOC *PAT* $(\sigma = 0, \theta = 1)$:

$$\frac{\partial \pi_i(r_i, r_j, r_k)}{\partial r_i} = \frac{\frac{1}{10}(c^H - c^L)(1 - \frac{1}{10} r_j^{0.5})(1 - \frac{1}{10} r_k^{0.5})}{r_i^{0.5}} - 1 = 0.$$

Solving these equation systems for each treatment leads to the equilibrium investments presented in Table 2.

SOC general case:

$$\frac{\partial^2 \pi_i(r_i, r_j, r_k)}{\partial r_i^2} = -\frac{\frac{1}{40}(c^H - c^L)(1+\theta)(1 - \frac{1}{10} r_j^{0.5})(1 - \frac{1}{10} r_k^{0.5})}{r_i^{1.5}} < 0.$$

For the given parameters SOC is always negative.

D3: Added welfare

In general, expected added welfare through R&D is given by

$$W^e(r) = (1 - \prod_{i=1}^{n}[1 - F(r_i)])T\Delta c - \sum_{i=1}^{n} r_i,$$

where Δc gives the increase in welfare if at least one firm succeeds in R&D,[50] which occurs with probability $1 - \prod_{i=1}^{n}[1 - F(r_i)]$, and $\sum_{i=1}^{n} r_i$ gives the total R&D investment costs in the industry.

Expected added welfare for symmetric R&D investment levels r_i=r is given by

$$W^e(r) = (1 - [1 - F(r)]^n)T\Delta c - nr.$$

[50] The additional welfare of a lower market price if at least one firm's innovation is successful compared to the initial higher price is given by $(\overline{p} - c^L) - (\overline{p} - c^H) = c^H - c^L \equiv \Delta c$.

D4: Comparative statics of the optimal investment

The optimal investment is characterized by the first order condition:

$$\frac{\partial \pi_i(r_i, r_j, r_k)}{\partial r_i} = Q(c^H - c^L)(1+\theta) f(r_i)(1-F(r_j))(1-F(r_k)) - (1-\sigma) = 0$$

With the implicit function theorem $\left(\frac{dr_i}{dr_j} = -\frac{\frac{\partial^2 \pi_i(r_i, r_j, r_k)}{\partial r_i r_j}}{\frac{\partial^2 \pi_i(r_i, r_j, r_k)}{\partial r_i^2}} \right)$ we can show that the firm's investment decreases with an increase in the rival's investment:

$$\frac{\partial^2 \pi_i(r_i, r_j, r_k)}{\partial r_i r_j} = -Q(c^H - c^L)(1+\theta) f(r_i) f(r_j)(1-F(r_k))$$

$$\frac{\partial^2 \pi_i(r_i, r_j, r_k)}{\partial r_i^2} = Q(c^H - c^L)(1+\theta) f'(r_i)(1-F(r_j))(1-F(r_k))$$

$$\frac{dr_i}{dr_j} = \frac{f(r_i) f(r_j)}{f'(r_i)(1-F(r_j))} < 0 .$$

A3: Additional experimental results

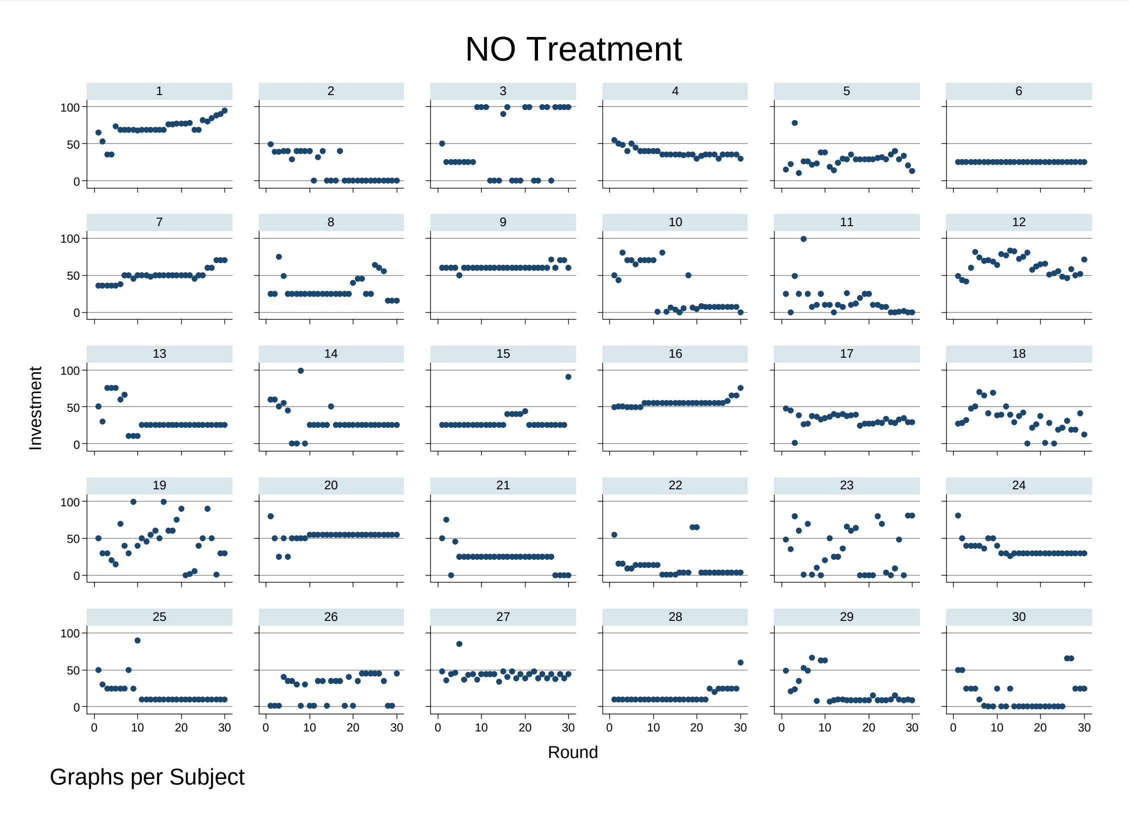
Mark-ups of the firms are defined as *price – costs* and represent the firm's incentive to innovate. Recall that theoretically predicted mark-ups if there are zero, one, two and three innovations are 0, 399, 0, and 0 points in the first market; 0, 0, 0, and 0 in the second market for *NO* and *SUB* due to imitation, and 0, 399, 0, and 0 in the second market for *PAT*. Table A4 shows that mark-ups deviate to some extent from Nash predictions. Hence, observed mark-ups are higher when zero-mark-ups are predicted if there are no, two, or three low cost firms and slightly lower when mark-ups of 399 points are predicted if there is a sole low cost firm. Moreover, deviations appear to be systematic. First, observed average mark-ups are always larger in the first than the second market period for a given cost structure and treatment, except when there is only one low cost firm in *PAT*.[51] Second, mark-ups rank in a specific ascending order of cost structures: Three low cost firms achieve somewhat higher mark-ups than three high cost firms, and two low cost firms have somewhat higher mark-ups than three low and high cost firms, i.e., it holds *zero* < *three* < *two* < *one* low cost firms for a given market

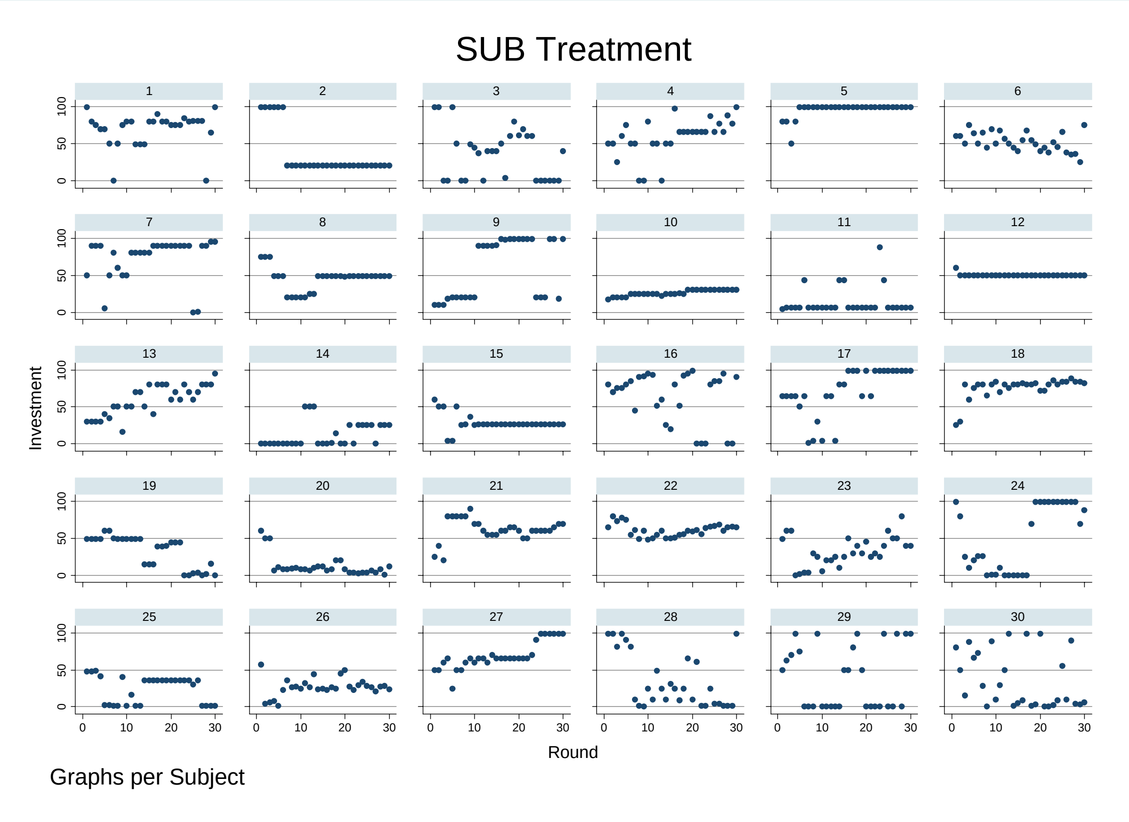
[51] This result is driven by the higher price setting in the first market.

period and treatment. Table A4 shows that in terms of providing incentives to invest in R&D *PAT* is not only the best policy for a sole innovating firm as the observed (theoretically predicted) sum of mark-ups of both periods amounts to 788.87 (798) compared to 407.76 and 380.26 (both 399) in *NO* and *SUB*, but furthermore it also yields the highest sum of mark-ups for all other cost structures (zero, two and three). In *SUB* mark-ups over both periods are lowest. Note that here incentives to innovate refer to a 'pure' mark-up effect (and target solely at the revenue side of firms) neglecting incentives which arise from a reduction of investment costs.

Figures and Tables

Figure A1: Individual investment behavior





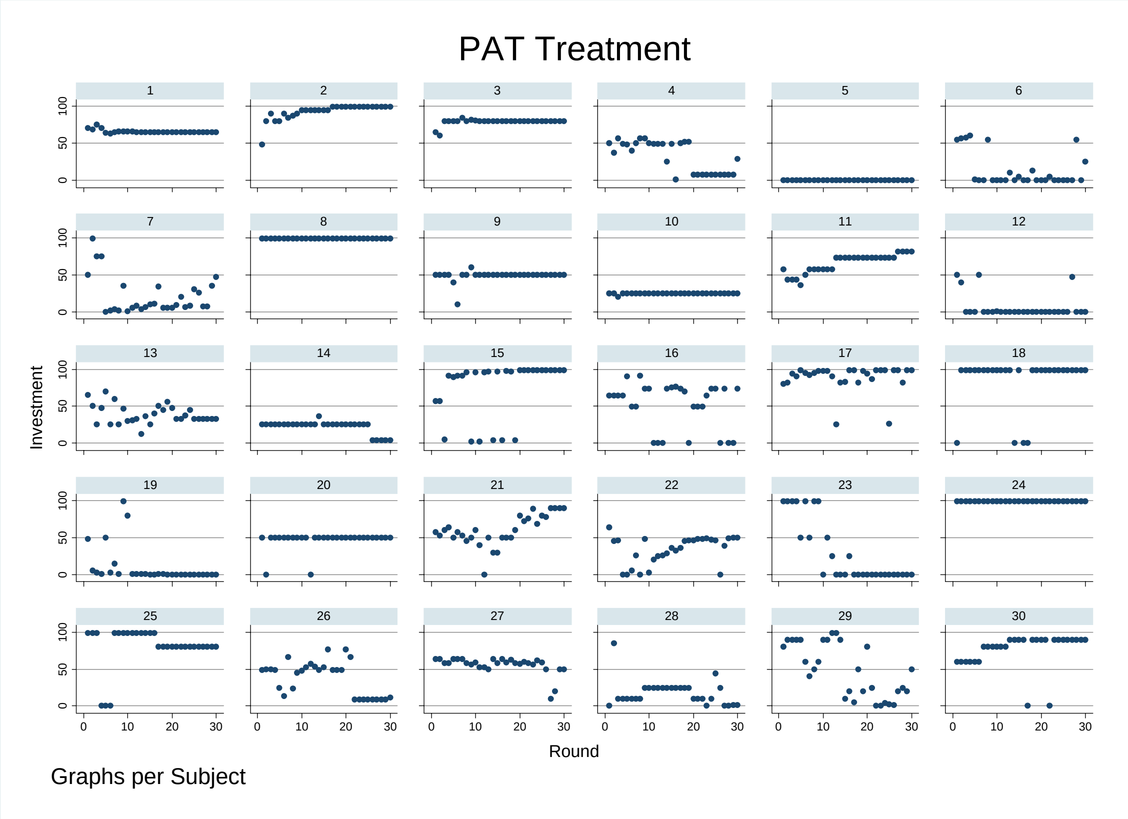
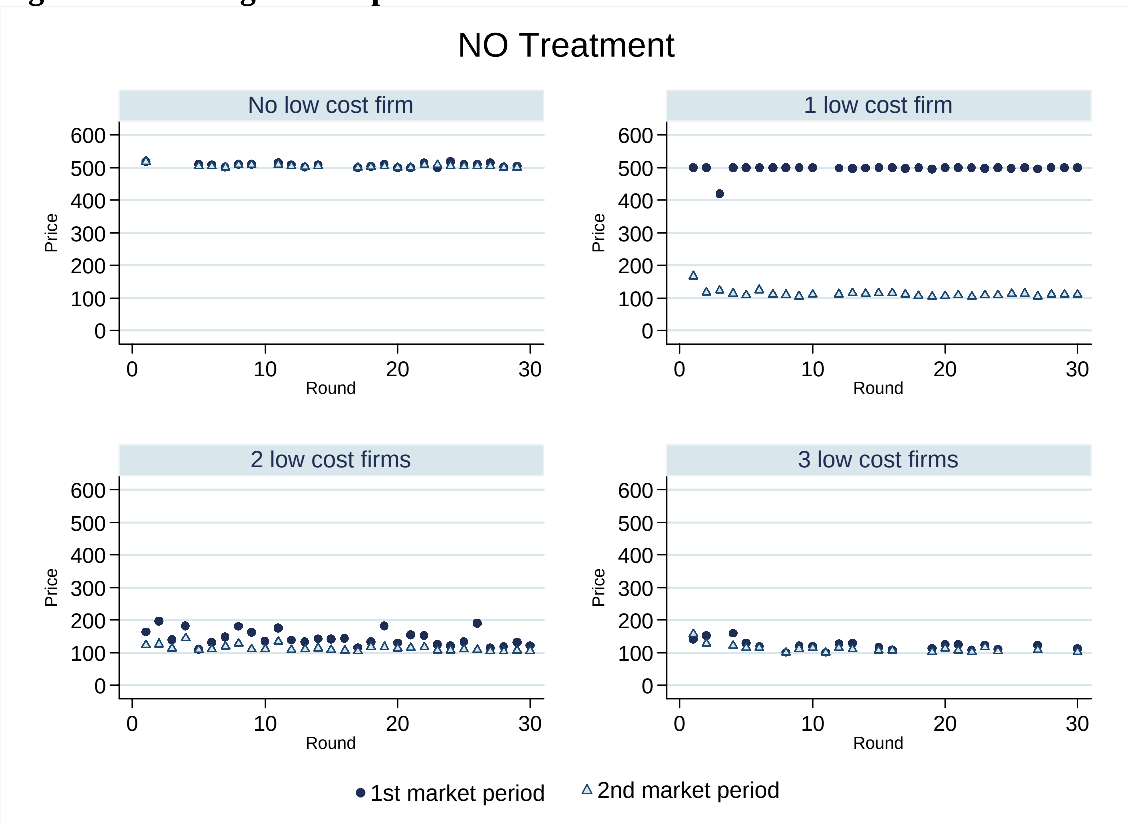
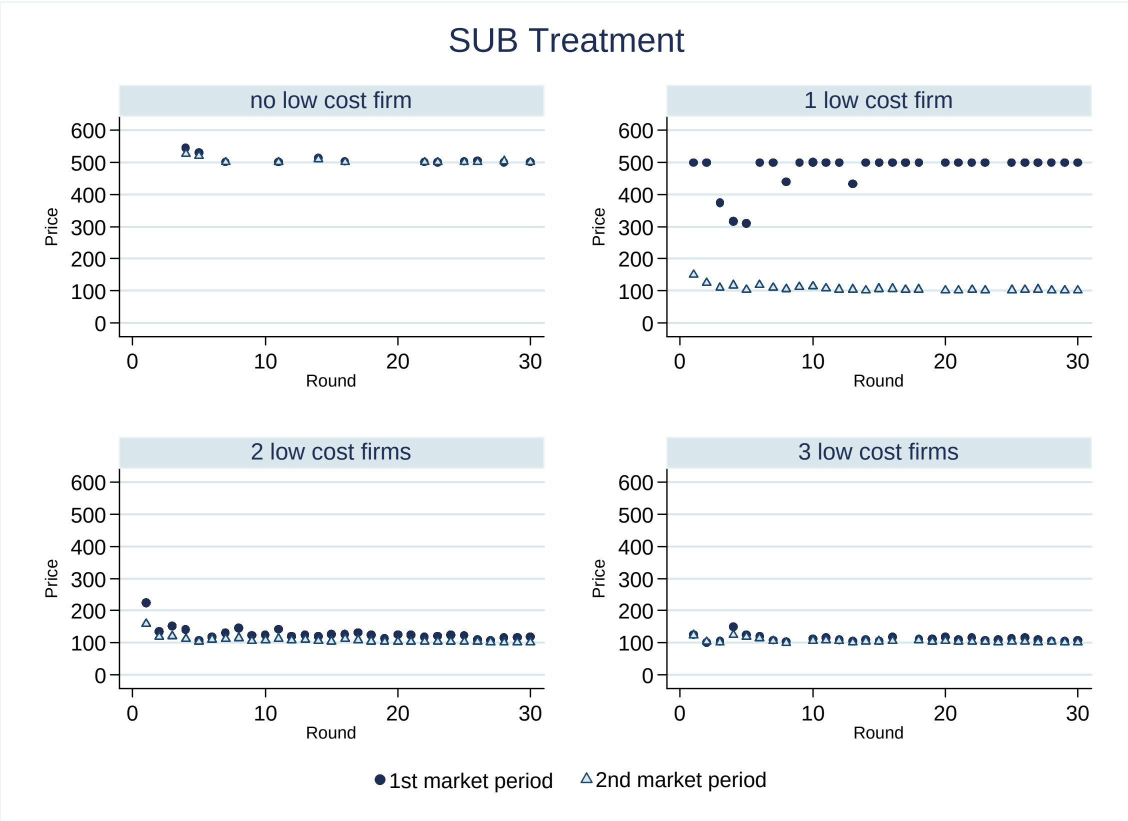


Figure A2: Average lowest prices for each cost structure over rounds





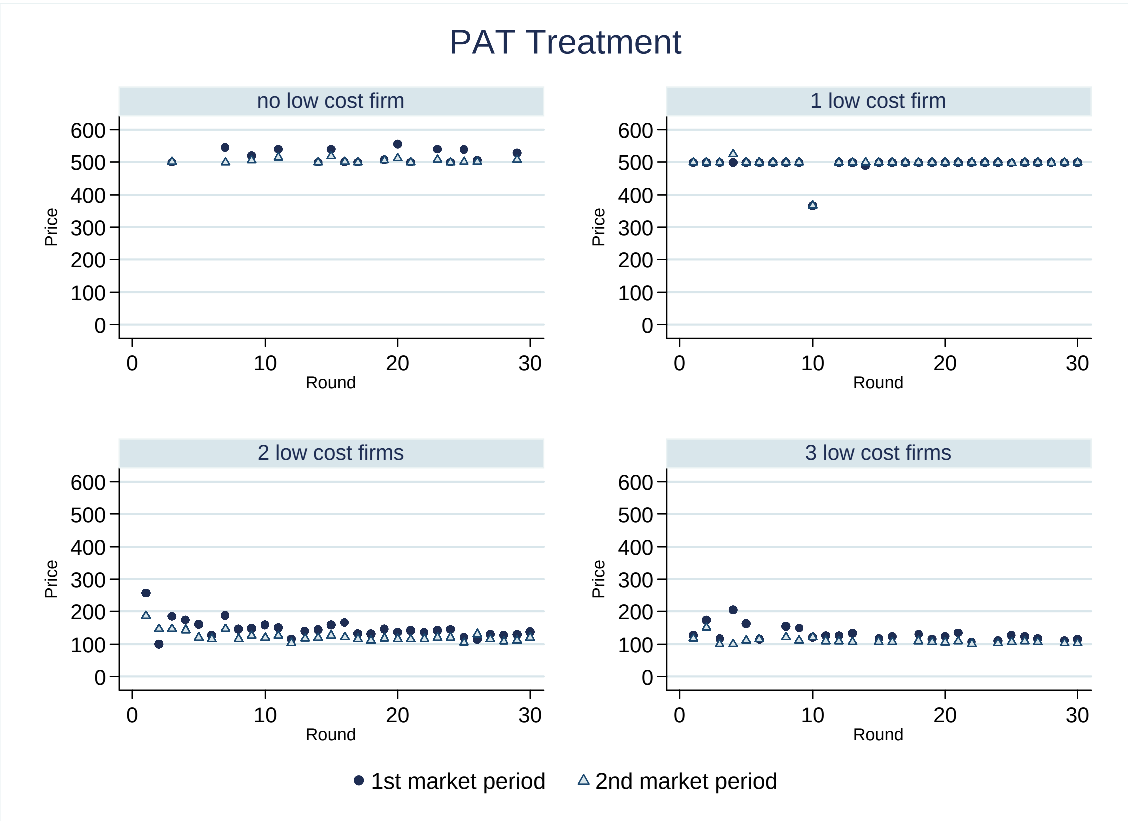


Figure A2 gives average lowest prices for each cost structure in the 1*st* and 2*nd* Bertrand markets for each round. In case there is no entry there was no group consisting of that special number of low cost firms in that specific round. Note that the number of low cost firms only refers to the cost structure in the first market period (i.e., it refers to the number of initially successfully innovating firms). The labeling specifies different cost structures after the investment stage and gives prices for both periods of the Bertrand market.

Table A1: Discrete symmetric and asymmetric Nash equilibrium investment levels

Treatment	Investment decision		
	r_i	r_j	r_k
NO	0	0	99
	20	25	30
	20	26	29
	20	27	28
	21	24	30
	21	25	29
	21	26	28
	21	27	27
	22	23	30
	22	24	29
	22	25	28
	22	26	27
	23	23	29
	23	24	28
	23	25	27
	23	26	26
	24	24	27
	24	25	26
	25	**25**	**25**
SUB	0	0	99
	37	**37**	**37**
PAT	0	0	99
	37	**37**	**37**

$\Delta c = 399$ is taken for the computation of equilibria (compare footnote 25).

Table A2: OLS regression results with *CR1* as base category

	(1)	
Investment	coefficient	(St. er.)
NO	44.08^{***}	(5.057)
SUB	57.41^{***}	(3.272)
PAT	74.74^{***}	(0.748)
$CR0_{t-1}*NO$	-15.82^{***}	(2.870)
$CR0_{t-1}*SUB$	-25.63^{***}	(1.862)
$CR0_{t-1}*PAT$	-46.84^{***}	(4.337)
$CR2_{t-1}*NO$	-3.872^{*}	(2.169)
$CR2_{t-1}*SUB$	-3.171	(2.543)
$CR2_{t-1}*PAT$	-8.722^{***}	(2.585)
$CR3_{t-1}*NO$	-9.592^{**}	(4.391)
$CR3_{t-1}*SUB$	-1.834	(2.590)
$CR3_{t-1}*PAT$	-15.49^{***}	(1.304)
N	2610	
R^2	0.218	

Standard errors in parentheses are corrected for matching group clusters. Cost reduction dummy variable '*CR1*' is dropped as base category. As we drop the constant in the estimated models, the reported R^2 is taken from the (analogous) model (2) as presented in Table A3.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A3: OLS regression results with *SUB* as base category

	(1)		(2)		(3)	
Investment	coefficient	(St. er.)	coefficient	(St. er.)	coefficient	(St. er.)
NO	-3.521	(3.336)	-3.521	(3.340)	-8.171**	(2.855)
PAT	-3.881	(4.222)	-3.881	(4.227)	-7.511*	(4.008)
_cons	31.78***	(2.086)	31.78***	(2.088)	34.84***	(1.626)
CR_{t-1}*NO	-12.16***	(3.813)			-11.994***	(3.709)
CR_{t-1}* PAT	14.14**	(4.967)			14.316**	(4.915)
CR_{t-1}	23.34***	(3.096)			23.088***	(2.983)
$CR1_{t-1}$*NO			-9.803**	(3.422)		
$CR1_{t-1}$*PAT			21.22***	(4.720)		
$CR1_{t-1}$			25.63***	(1.862)		
$CR2_{t-1}$*NO			-10.50**	(4.472)		
$CR2_{t-1}$*PAT			15.67***	(4.660)		
$CR2_{t-1}$			22.45***	(3.652)		
$CR3_{t-1}$*NO			-17.56***	(4.201)		
$CR3_{t-1}$*PAT			7.564	(5.153)		
$CR3_{t-1}$			23.79***	(3.160)		
round1_15**NO*					9.393***	(2.441)
round1_15**PAT*					7.290**	(2.840)
round1_15					-6.004***	(1.888)
N	2610		2610		2610	
R^2	0.211		0.218		0.215	

Standard errors in parentheses are corrected for matching group clusters. Treatment dummy variable '*SUB*' is dropped as base category.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A4: Average mark-ups in the Bertrand markets

Bertrand markets	Treatment	Number of innovating firms			
		Zero	*One*	*Two*	*three*
1^{st}	*NO*	8.37	394.37	46.13	24.14
	SUB	7.36	373.00	27.77	12.69
	PAT	19.29	393.88	49.20	31.36
2^{nd}	*NO*	4.66	13.39	14.23	13.55
	SUB	4.93	7.26	8.77	6.12
	PAT	4.53	394.99	24.48	11.13
Both periods	*NO*	13.03	407.76	60.36	37.69
	SUB	12.29	380.26	36.54	18.81
	PAT	23.82	788.87	73.68	42.49

The number of innovating firms indicates the successfully innovating firms after the investment stage (i.e., low cost firms in the first market period), but does not refer to imitating firms in the second market period.

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